Ecosystem Models for Development

Workshop Report*
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FOREWORD

The Environment and Policy Institute (EAPI) of the East-West Center was established in October 1977 to conduct research and education programs through multinational collaboration on the environmental aspects of policy and decision making in the East-West region. The program of the Institute emphasizes (1) analysis of various policies (e.g., economic development, maritime jurisdiction) to illuminate their dependence and impacts on natural systems and thus on the objectives of the policies, and (2) assessment of scientific and technical information about natural systems for more coherent policy formulation and implementation through planning and management. This systematic approach avoids the polarization of environmental values versus sectoral goals.

A major focus of EAPI's work has been on human ecology—the study of human-environment interactions. The interplay between social and ecological systems in the tropics is particularly complex. Study of these factors requires a blend of the natural and social sciences to a degree not usually found in academic and research institutions. Because this is a new and as yet incompletely developed field, relatively few scholars are familiar with its conceptual framework or trained in its research applications.

A program has been established in EAPI with two primary goals: (1) development of conceptual approaches to human ecology suited for use in applied research on agricultural systems in Southeast Asia, and (2) formation of a cadre of Southeast Asian scientists trained to apply this research approach. Since 1980, a series of workshops, working groups, and conferences have been held throughout the region to disseminate information about human ecology to active researchers and to draw on the experiences of researchers in the region to further develop its applicability to the analysis of issues of rural resource development and management. Accompanying these activities have been continuing efforts to foster a strong agroecosystem research network in Southeast Asia.

These efforts came to fruition in mid-1982 with the formation of the Southeast Asian Universities Agroecosystem Network (SUAN), a loosely structured association of key research and teaching institutions in Indonesia, the Philippines, and Thailand. By pooling their separate proficiencies into a single regional network, SUAN member institutions have created what is potentially one of the strongest human ecology research capabilities in the world. In late 1982, scientists from SUAN projects, EAPI, and several other institutions met with several dozen Chinese scientists in Kunming and Canton to exchange information and ideas about applying ecological principles to agricultural research.

This Workshop Report is the outgrowth of that meeting in China, and there have also been significant results as new ideas have been tried. Additional exchanges of scientists and information have occurred among the participating institutions, and follow-up human ecology workshops have been agreed upon. Through activities such as these, we strive to contribute to a creative resolution of issues that are vital to the national and international interests of countries in the region.

William H. Matthews, Director
Environment and Policy Institute
East-West Center

PREFACE

A workshop on "Ecosystem Models for Development" (Chinese title: "Make Use of Ecological Principles to Increase Agricultural Production") was jointly sponsored by the East-West Environment and Policy Institute (EAPI) and the Chinese Ministry of Urban and Rural Construction and Environmental Protection (MURCEP). It was the second of three joint workshops that William H. Matthews, EAPI director, and Li Chaobo, a senior Chinese environmental official, agreed to hold during their discussions in Beijing in 1980.

The theme of the Workshop had been suggested by Qu Geping, deputy director of the Environmental Protection Office—the predecessor institution to the Environmental Protection Bureau in MURCEP*—to Dr. Matthews in a letter dated 18 February 1981. Mr. Qu wrote, "We suggest to initiate an intensive survey . . . of some of the most promising renewable resources worth developing for the Asian developing countries. We are just beginning to formulate a working program . . . a tentative plan of topics may cover biogas, algae, kelp, fast growing wood, industrial crops, and ecological farms."

As these topics were compatible with the orientation of EAPI's Program Area on Human Interactions with Tropical Ecosystems (HITE), Dr. Matthews requested A. Terry Rambo, the HITE program area coordinator, to assume lead responsibility for organizing the Workshop. John A. Dixon, EAPI research associate, served as assistant workshop coordinator.

At the suggestion of EAPI, the Workshop was held in south China, with the first week spent in and around Kunming, Yunnan Province, and the second week in Guangdong Province. In addition to three plenary sessions and nine working group sessions, field trips to three "ecological farms" were organized. A number of excursions to scenic, cultural, and economically interesting places were also organized.

The EAPI delegation was made up of ten participants. Three were from EAPI (A. Terry Rambo and John A. Dixon, research associates, and George W. Lovelace, research fellow), one from the East-West Population Institute (Peter N. D. Pirie), and one from the University of Hawaii College of Tropical Agriculture and Human Resources (Joseph P. O'Reilly). The other participants were scientists cooperating with HITE's network on human ecology research on tropical agroecosystems in Southeast Asia. They included Terd Charoenwatana (Khon Kaen University, Thailand), Gordon R. Conway (Imperial College, London), Rokiah Talib (Universiti Malaya), Percy Sajise (University of the Philippines at Los Baños), and Manu Seetisarn (Chiang Mai University, Thailand). Disciplines represented included agricultural economics, anthropology, ecology, economics, environmental psychology, plant breeding, population geography, and sociology. The EAPI team was thus a highly interdisciplinary one, with both natural and social scientists involved.

*MURCEP, which consists of 18 bureaus, was formed during the Chinese governmental reorganization in early 1982. It incorporated the Environmental Protection Office that had been the institution with which EAPI initiated its cooperative activities in China. This Workshop was organized by the Bureau of Foreign Affairs and the Bureau of Environmental Protection within MURCEP.

In contrast, the 36-member Chinese team was made up almost entirely of natural scientists, primarily agronomists, botanists, biologists, engineers, entomologists, foresters, and soil scientists. A geographer and an ethnobotanist were the only Chinese scientists with any explicit social science orientation, although a number of others included social and economic considerations in their papers. In addition, a number of administrative cadre, Environmental Protection Bureau staff, and journalists were also present. After the first week, Harvey Croze of the United Nations Environment Programme in Nairobi joined the Workshop as an observer.

OVERVIEWS OF THE WORKSHOP

Overview by the EAPI Organizers

In the opening plenary session, chaired by Professor Qu Zhongxiang, a senior botanist from the Biology Department of Yunnan University; Mr. Zhang Shuzhong, vice-president of the Chinese Society of Ecology; and A. Terry Rambo, EAPI workshop coordinator, each made brief opening remarks. These were followed by keynote presentations of Professor Qu's paper, "A Tentative Plan for the Development of Ecological Farms in China," and Dr. Rambo's paper, "Ecosystem Models for Development: An Introduction to Human Ecology as a Methodology for Development Research, Planning, and Analysis." These papers provided a general introduction to the theme of the Workshop.

Following the opening session, the Workshop participants were divided into three working groups, each composed of three or four EAPI-sponsored participants and ten to fifteen Chinese participants. Each group had one EAPI and two Chinese group leaders and was assigned four or five papers to discuss in detail, following summary presentations of each paper by its author.

Following the first six working group sessions in Kunming, an interim plenary session was held, bringing members of all the groups together again. The rapporteurs from each of the groups then presented a summary of their discussions to date. Dr. Rambo, as session chairman, in turn, made some observations on areas of consensus and "contradiction" in thinking about applying ecological principles to agricultural development.

Dr. Rambo noted that all participants seemed to be in agreement that agroecosystems are very complex systems involving both natural and social components. Three key problem areas requiring further discussion were identified:

- agricultural/forest ecosystem interactions,
- upland/lowland ecosystem interactions, and
- ecosystem/social system interactions.

Several areas that had also been identified where significant contradictions or trade-offs between objectives in agricultural development must be considered were:

- extensification/intensification,
- productivity/sustainability,
- monoculture/polyculture,
- closed/open ecosystems,
- national economic growth/quality of individual life,
- single model of ecological farms/diverse locally adapted models,
- applied research/basic research, and
- natural science research/social science research.

Mr. Zhang Shuzhong responded to these remarks on behalf of the Chinese group. He emphasized the need to integrate more completely the natural and social sciences in future Chinese research on ecological farming and also on the need to employ a comprehensive systems framework of the sort being used by the EAPI participants in their own research on agroecosystems in Southeast Asia.

Following the interim plenary, the Workshop venue was shifted from Kunming to Guangzhou (Canton) for field trips and additional discussion

sessions. For the final session, attention was focused on possibilities for future cooperation. The EAPI participants suggested that the following four basic problem areas should be considered in developing future joint activities:

- Research on better management of hilly areas/uplands and analysis of upland/lowland ecosystem interactions.
- Comparative analysis of a variety of different types of agroecosystems.
- Increasing cooperation between natural and social sciences and the use of human ecology as a research framework.
- Emphasis on tropical and subtropical agroecosystems of southern China, particularly Yunnan Province.

In the final plenary session, Dr. Rambo presented a summation in which he described three fundamental differences in the initial Chinese and EAPI team approaches to agroecosystem research:

- The Chinese approach is highly pragmatic and problem-oriented. Its emphasis is on finding single solutions to already identified critical problems, e.g., biogas generators are proposed as the solution to rural energy shortages. In contrast, the EAPI approach is less direct. It asks, "How can agroecosystems be best analyzed in order to identify problems needing solutions?"
- The Chinese approach is rather specialized, and research is carried out within conventional disciplinary boundaries. The EAPI approach is more generalized and interdisciplinary, reflecting the view that agricultural development research is a problem in human ecology.
- The Chinese had applied the term "ecological farm" to only a specialized, high-technology form of agriculture. The EAPI team is concerned, however, with understanding all forms of agriculture, both modern and traditional, in ecological terms.

These initial differences had been good rather than bad "contradictions" because they had provided great stimuli for discussion, leading to the synthesis that was achieved in the final meeting about future cooperation in studying the application of ecology to agricultural development research.

Mr. Zhang Shuzhong presented the concluding remarks for the Chinese team. Particular concern was displayed for the development of more interdisciplinary work on agroecology. The Chinese team also prepared their own written summary of the Workshop. This summary is included in the present report.

Future activities between EAPI and the Chinese were also discussed. It was agreed that the initial task was the publication of the papers presented in both Chinese and English versions. MURCEP has prepared a Chinese-language publication that will appear in 1984 with all of the Workshop papers.* Because of various constraints, it is not feasible to publish the English version of all the papers. Rather, this Workshop Report contains short summaries of each paper and the originals can be obtained by writing directly to EAPI. In addition, Dr. Rambo has prepared an interpretative essay, "Human Ecology Research on Rural Development," that summarizes many of the common threads from the Workshop papers and places them in a human ecology framework. This essay is also included in this report.

Overview by The Chinese Cosponsors

The international academic "Workshop on Ecosystem Models for Development," cosponsored by the Ministry of Urban and Rural Construction and Environmental Protection of the People's Republic of China and the East-West Environment and Policy Institute of the United States of America, opened in Kunming on 27 September 1982. The Workshop was divided into

*This book is titled *Proceedings of the International Workshop on Agricultural Development by the Use of Ecological Principles,* published by the Beijing Environmental Protection Magazine Press.

two sessions, the first being held in Kunming from 27 September to 3 October, and the second in Guangzhou from 4 to 11 October. Attending the Workshop were 36 Chinese representatives and 11 foreign representatives from the United States, Britain, Malaysia, the Philippines, and Thailand. Nineteen papers were presented at the Workshop; nine were from the Chinese participants and ten from the foreign guests. All the participants agreed that the Workshop was a success and that they have learned a great deal of useful information from each other. They found that the Workshop was of realistic significance not only for China but also for other countries. In particular, it is of far-reaching significance for the tropical and subtropical countries in Asia.

In real earnest the participants actively took part in the discussions for the Workshop. A friendly atmosphere prevailed throughout the discussions, although differences occurred at times. When the meeting was not in session, the participants also had free exchanges of views, talking and laughing during their conversations. Therefore, the Workshop is, at the same time, an academic seminar and an opportunity for the scholars and experts from various countries to build friendly ties with each other.

While focusing on the main topic of "Ecosystem Models for Development," the discussions covered a wide area involving some dozen disciplines such as human ecology, environmental economics, environmental psychology, agricultural ecology, botanic ecology, ethnobotany, and environmental management. Hence, the first characteristic of the Workshop is the discussion of a single academic question (i.e., the development of agricultural production using ecological principles) by multidisciplinary scholars and experts. This is beneficial to achieving depth and width in the exchanges.

Participants at the Workshop not only elaborated theoretically on the development of agricultural production by applying ecological principles but also visited some Chinese farms that basically conform to ecological principles. Among them were the No. 2 State Farm of Kunming, the Third Production Team of Xinfu Brigade in Leiliu People's Commune, Shunde County, on the outskirts of Guangzhou, and the Guangming Livestock Farm in Shenzhen. After the visits, discussions were held to analyze the farms from a theoretical point of view. Participants also made some good suggestions as to how to improve the work on the farms. Hence, the second characteristic of the Workshop is, to use a Chinese idiom, "combining theory with practice."

During the Workshop, questions in natural science, as well as those in social sciences, were discussed; for instance, population problems; *Feng-shui* (geomancy, a folk belief system relating locational and environmental variables to fortune or good luck); and the culture and education of the farmers. Hence, the third characteristic of the Workshop is the joint exploration of environmental problems by using both natural and social sciences. Extensive issues were discussed at the Workshop. Summaries of these discussions follow.

The Concepts, Tasks, and Economic Benefits of Ecological Farms

Applying the principles of natural science, social science, and economics, Professor Qu Zhongxiang, a Chinese biologist, described the concepts, tasks, and economic benefits in the development of ecological farms in China. He pointed out, "By applying ecological principles, it manages to exploit, utilize, and administer the natural resources in line with local conditions. Also, it adopts various techniques to raise the rate of biological energy and the recycling rate of waste products." He also pointed out, "The theoretical basis for ecological farms is constantly raising the transformation efficiency from solar energy to biological energy and from nitrogenous resources to high protein, and accelerating the recycling process of energy and materials in ecosystem to acquire its ideal norm."

At the discussion, Professor Conway suggested four characteristics an ecological farm should have in its development—stability, sustainability, equitability, and productivity. He expounded on stability and sustainability in detail. He proposed that ecologists should help ecological farms raise their sustainability and stability. Other experts

and scientists also gave their attention to these two issues.

After visiting Kunming No. 2 State Farm, both Chinese and foreign participants unanimously pointed out that this farm should strengthen its primary production and make better use of its land. The participants believed that the New Energy Village in Shunde County, Guangdong Province, is a typical Chinese ecological farm with high economic efficiency. Some participants also pointed out that economic quantification of input and output should be made. Dr. Rokiah Talib said that social problems should also be taken into consideration. For instance, participation in labor by children will affect their cultural study.

The Role of Human Ecology in the Development of Ecological Farms

Dr. Terry Rambo of the East-West Environment and Policy Institute and other scientists described the role of human ecology in development as a process in which the human society and the natural ecosystem interact. The flows of energy in an ecosystem are not solely from the sun to plants to animals, but there is also the flow from the ecosystem to the social system and from the social system to the ecosystem. In other words, the ecosystem and social system are not two isolated, closed systems but are two interrelated systems that interact in a complex macrosystem. The two systems are linked through the flows of energy, material, and information. Each system consists of several elements—soil, water, air, bio-organisms, plankton, weeds, and crops in the ecosystem; population, language, cultural beliefs, education, health, technical levels, and social structure in the social system. All components are interrelated and interact. Any change in one component not only affects the other components in the same system but also affects the other system, causing changes in both systems. When the environmental objectives of an ecosystem are considered, all related components in the two systems should be taken into account. A comprehensive and rational program can be worked out only if natural scientists, social scientists, and experts of related disciplines are invited to participate in the discussion and the farmers' opinions are heard. Dr. Rambo said, "The real world is a complex one. The mistake we made was to use simple models to deal with complex ecosystems." The Chinese colleagues agreed with this point.

Mr. Pei Shengji of the Yunnan Institute of Tropical Botany presented his paper, "A Preliminary Study of Ethnobotany in Xishuang Banna." The paper has made a contribution to human ecology and aroused the interest of both Chinese and foreign scientists.

Dr. Joseph O'Reilly of the University of Hawaii at Manoa discussed the concept of "quality of life." He believes that it is mainly the farmer's quality of life, not the productivity, that is the criterion by which we determine whether a farm is good or not. His view is that the volume of a country's Gross National Product (GNP) cannot totally reflect the quality of life in that country. He thinks the indices for the quality of life cover several areas. They should be expressed with a curve showing the relationship between GNP and, for example, the quantity of energy consumption, the quality of protein consumption, level of universal education, average life span, or crime rate. He thinks that when planning agricultural development, it should be made clear that the aim for the development of agricultural production is to raise the people's quality of life in the area.

Dr. Peter Pirie of the East-West Population Institute presented the paper, "Population Dynamics, Agroecosystems, and Agricultural Innovation." He studied the relationship between population density, land tenure systems, human fertility and mortality rate, changes in population structure, and the agroecosystem. Dr. George Lovelace of the East-West Environment and Policy Institute discussed the impact of culture, beliefs, customs, and habits on agricultural development in a paper titled "Cultural Beliefs and the Management of Agroecosystems." He pointed out particularly that China's *Fengshui* (geomancy) is in line with the laws of nature in certain aspects.

Discussing Agroecosystems Based on Actual Cases

The majority of the papers presented were on agroecosystems. They described the models of particular agroecosystems in different countries. Professor Zhong Gongfu, of the Guangzhou Institute of Geography, discussed the ecological model of the field-pond system of the low-lying sandy land at the Pearl River estuary in a paper titled "The Ecological Patterns in the Field-Pond System of the Low-Lying Sandy Land of Both Sides of the Zhujiang (Pearl River) Estuary." He described the comprehensive benefits of such a field-pond system. He believes that the field-pond system not only improves farming conditions but can also achieve optimum results under different circumstances, thus gradually moving toward the rationalization of agricultural structure and production layout. So long as the production of grain is guaranteed, the proportion of rice fields to sugarcane fields can be adjusted, fish ponds enlarged, and more pigs and poultry raised. The growing of rice and sugarcane, the breeding of fish, and the raising of pigs and poultry should be coordinated so that a good economic cycle and material cycle are formed and promoted. Such is a feasible approach to transforming the low-lying sandy areas on both sides of the Pearl River estuary. Mr. Long Yiming of the Yunnan Research Institute of Tropical Botany, Academica Sinica, presented his paper, "Ecological Effects and Economic Results of the Artificial Plant Community." On the basis of the data obtained since 1960 in fixed experimental fields, he discussed the ecological effects and economic results of some different combinations of artificial plant communities.

The Workshop showed great interest in the paper, "Ecological Approaches to Managing Degraded Uplands in the Philippines," presented by Dr. Percy Sajise of the University of the Philippines at Los Baños. He described some upland regeneration strategies that included low input and legume-based upland regeneration strategy, site characteristics and reforestation, forage-legume and livestock production schemes, and *Leucaena*-based upland cropping systems. The participants thought that his paper is of certain reference value for the restoration of the degraded uplands in tropical and subtropical areas.

Extensive discussions have also been focused on the following papers: "Agricultural Land Development and Forest Clearance in Peninsular Malaysia" by Dr. Rokiah Talib of Universiti Malaya; "Agricultural Ecology Research in Northeast Thailand" by Dr. Terd Charoenwatana of Khon Kaen University, Thailand; "The Correlation Between the Exploitation of the Tropical Forest in Southern Yunnan and the Water and Soil Conservation" by Mr. Wang Huihai and others of the Yunnan Research Institute of Tropical Botany, Academica Sinica, and "A Preliminary Observation on the Creation of the Farmland Forest Network and Its Effects in Doumen County in the Pearl River Delta" by Liu Jihan of the Coordinated Group of the Farmland Forest Network Research of Guangdong Province.

Discussions on the Management of Ecological Farms

The participants also showed keen interest in two papers that introduced the managerial concept of ecological farms with systems analysis. The papers are "Identifying Key Questions for the Development of Tropical Ecosystems" by Dr. Conway from the Centre of Environmental Technology, Imperial College of Science and Technology, and "Systems Analysis of Agriculture in the Chiang Mai Valley" by Dr. Manu Seetisarn of Chiang Mai University, Thailand. Dr. Conway said in his paper:

> For the past few years I and my colleagues in Thailand have been endeavouring to find ways of analyzing ecosystem complexity in a more efficient and productive manner. Our focus has been agroecosystems but I believe the methods we have developed can be applied equally to other managed ecosystems —for example, to forests, grazing land, inland and marine fisheries. With suitable modifications I believe they can also be

applied to the task of environmental impact assessment of industrial and urban ecosystems.

He then elaborated on "procedure for analysis," "definition of objectives," "system definition," "guidelines," and "research, design, and implementation." All the participants agreed that the most desirable efficiency of energy and material flows can be achieved only when systems methods are applied.

A paper titled "Using Benefit-Cost Analysis to Evaluate Alternative Strategies for Developing Tropical Ecosystems" was presented jointly by Mr. Wang Yiting of the Chinese Research Academy of Environmental Sciences and Dr. John A. Dixon of the East-West Environment and Policy Institute. They pointed out in their paper that the objective of economic cost-benefit analysis is to analyze and make monetary evaluation of the ecological and social trade-offs, in particular, the allocation and utilization of production resources to supply a scientific basis for decision making. The processes involve analysis and determination of the quantity of relevant factors, the placement of monetary values on those factors, and economic assessment. Attention should be focused on the spatial and time dimensions of the system under study, and both the short-term and long-term impacts should also be considered. Uncertainty and irreversibility should be taken into account as well. In actual application, consideration should also be given to economic systems and institutional factors with the help of multiobjective systems analysis.

Another paper, "A Study of the Basic Theory and Technical Methods to Assess the Efficiency System of Forests," was presented by Mr. Zhang Jiabin of the Exploration Team for Forest Resources in Yunnan Province. The paper began with a description of the natural process in the study of the various functions of a forest and analyzes these functional systems with reference to the goods and services provided to humans. Quantification and evaluation are done in accordance with the basic theories of some 40 disciplines including ecology, operations analysis, and mathematical statistics whereby fundamental principles and technical methods in the assessment of forest function systems are worked out. Elaborations are made on their actual applications with case studies in Nujiangzhou, Gongsha, Fugong, Bijan, and Lushuei of Yunnan Province. This paper received positive comments from the participants.

HUMAN ECOLOGY RESEARCH ON RURAL DEVELOPMENT

Introduction

Nineteen papers were presented at this Workshop. A glance at the list of titles indicates the wide range of topics discussed. Underlying the evident diversity, however, was a surprising degree of thematic coherence, reflecting the common commitment of participants to understanding rural development in ecological terms. The following interpretive essay attempts to show how the individual contributions are related to this theme and how together they can advance our understanding of a complex set of problems.

The tone is admittedly didactic because of the need to set forth in a highly compressed format an analytical framework that has as yet received only very preliminary formulation in available published sources. Most of the ideas have been discussed in various conferences, workshops, and meetings of the Southeast Asian Universities Agroecosystem Network (SUAN), but this is the first time that they have been put together into a single comprehensive description of the nature of human ecological research on agricultural ecosystems.

An Interpretive Essay (by A. Terry Rambo)*

Agricultural research conventionally has focused on improving the performance of individual components of the farming system, such as crop plants, fertilizers, and tools. In recent years, however, it has been increasingly recognized that components cannot be dealt with in isolation. Instead, it is seen that all are linked in an agricultural ecosystem, or agroecosystem, so that achieving their fullest potential for production requires attention to the system context in which the individual components function. The need for applying this viewpoint in agricultural research has been reinforced recently by a growing concern with the environmental implications of agricultural development, with questions arising about both the long-term sustainability of modern intensive farming technologies and their offsite impacts, including fertilizer and pesticide pollution.

Recognizing the systemic nature of agriculture, researchers have tried to apply ecological principles to enhancing productivity while minimizing environmental damage. As a result, agricultural ecology has emerged in recent years as a major new area of scientific inquiry, and agroecosystems have been recognized as an important topic for investigation both by ecologists and agronomists.

Unlike ecologists concerned with natural systems who have historically tended to exclude humans as an aspect of their research, agricultural ecologists have been forced to recognize from the start that they cannot understand the structure and functioning of agroecosystems without taking the activities of the farmers into account. As Gordon Conway points out in his paper, agroecosystems and other managed ecosystems are biologically simplified systems but "the inclusion of man, his social, cultural and economic activities, reintroduces complexity . . ." into these systems.

Natural scientists, however, lack the intellectual tools to deal with human activity, the primary concern of the social sciences. Understanding agricultural ecology, therefore, requires a fusion of the concepts and research methodologies of the natural and social sciences. Human ecology, the study of human interactions with the environment, offers a suitable intellectual framework for carrying out the required interdisciplinary research. The remainder of this introductory essay is devoted to showing how the broad range of papers presented by Chinese, Western, and Southeast Asian scholars at this Workshop can be incorporated into a human ecology perspective on agricultural systems.

Human Ecology

Although concern with human relations to the environment dates into antiquity, systematic scientific research on human ecology began only in the 1930s and received recognition as a major field of inquiry in the social sciences only in the 1960s. Although there are many different conceptual approaches to the study of human-environment interactions, the work of EAPI on agroecosystems has employed what has been labeled the "systems model of human ecology." In this model, the human ecosystem is composed of two semiautonomous subsystems: the human social system and the ecosystem (Figure 1). Although each subsystem is largely autonomous and changing according to its own internal dynamics, each is also influenced by its interactions with the other, so that change in one subsystem is likely to produce change in the other. Thus, human activities change the environment but human society also changes in response to environmental forces. The relationship is therefore dialectical, an endless process of co-evolution and adaptation.

Any social or ecological system can be analyzed

*In writing this essay I have drawn heavily on the work of all the participants in the joint EAPI/MURCEP Workshop on Ecosystem Models for Development. Their willingness to freely share their ideas is deeply appreciated. I would like to particularly stress my intellectual debt to Gordon Conway, who has strongly influenced my thinking about the nature of agroecosystems. Earlier drafts of this essay were read by John Dixon, George Lovelace, Richard Morse, and Theodore Smith. Their comments and criticisms have helped me to clarify this revision.

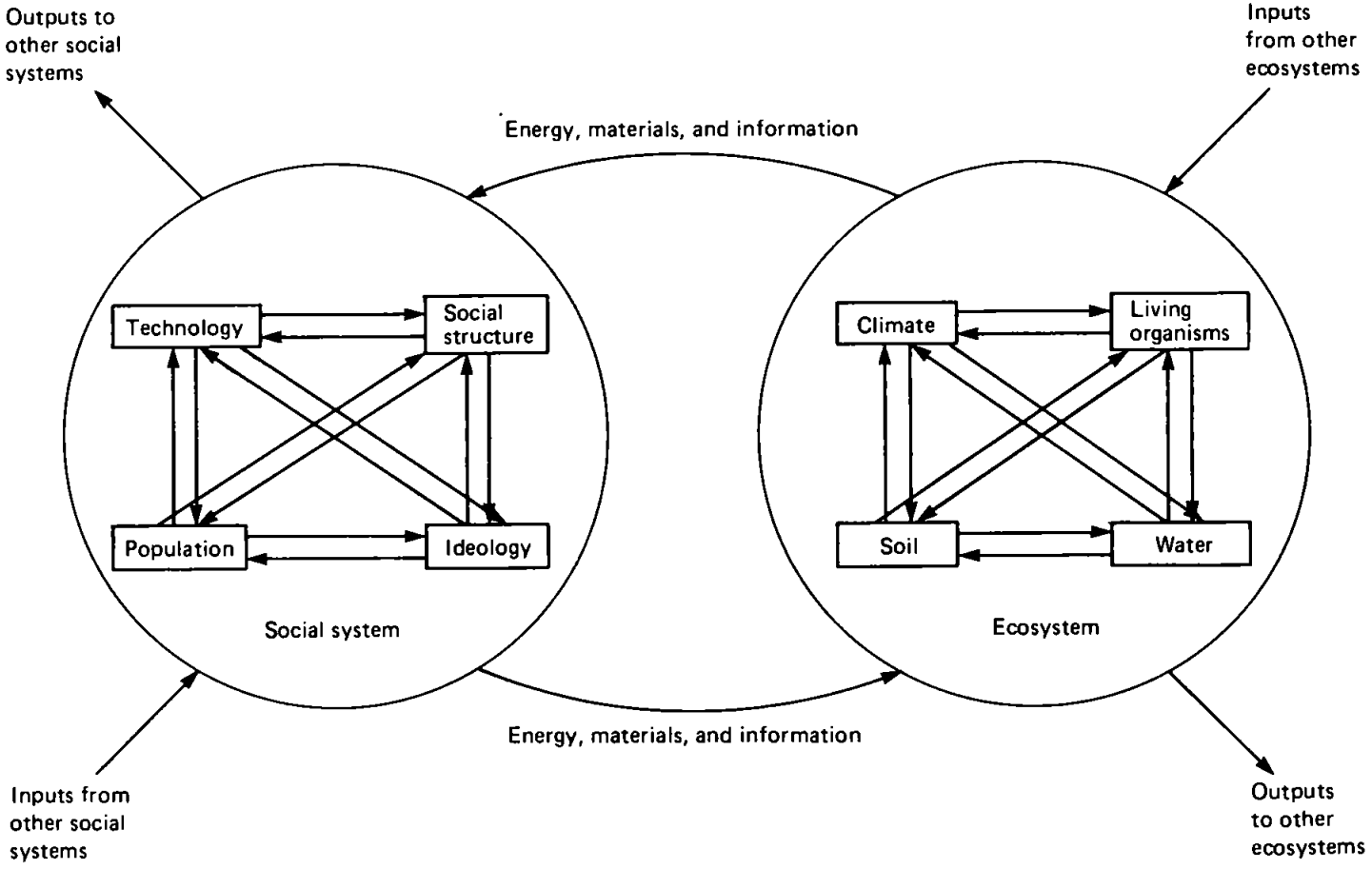


Figure 1. A systems model of human ecology.

in terms of its structure, functioning, and dynamics. Structure refers to the patterned relationships between the components that comprise the system. The components of an ecosystem include soil, water, and living organisms; those of a social system include population, technology, sociopolitical institutions, and ideology. System components are functionally related through the flow of energy, materials, and information. In an ecosystem, plants capture solar energy and transform it into chemical energy, which then may flow to herbivorous animals. Similarly, nutrient salts flow from the soil to the plants and then to the animals. Herbivores locate the plants they consume by tapping into information flows within the ecosystem, picking up visual or olfactory cues to the presence of their energy and nutrient sources in the habitat. The components of a social system are also articulated by energy, material, and information flows. Firearms, an item of technology, employ the chemical energy of gunpowder to drive a material projectile. A colonial ruling group may use such coercive technology to mobilize the labor force of the subject population to carry out actions in support of its ideological goals, but it can only do so effectively if it possesses accurate information about the location and sentiments of the affected population.

Dynamics refers to the processes of flux and change in the system and its evolution over time. Growing certain crops may maximize short-term productivity, for example, but, by causing soil erosion, lead to long-term degradation in ecosystem productivity. Rapid increase in human population size may maximize short-term military power but, by aggravating class contradictions, lead to social unrest and consequent reduction of the ability of the social system to respond to external threats. Such internal contradictions may also lead to replacement of traditional forms with new modes of production and social relations, just as competition between organisms within an ecosystem may accelerate evolutionary processes.

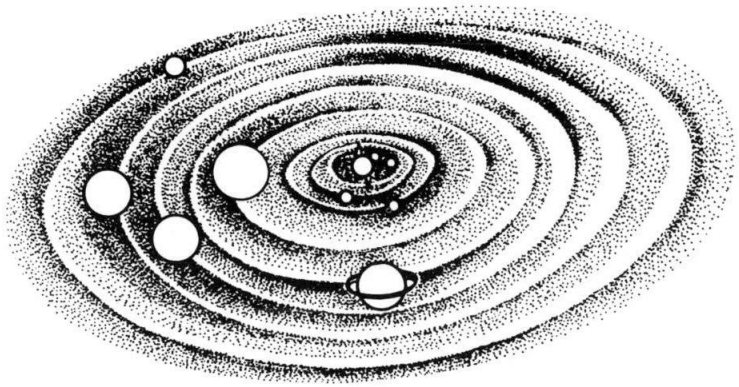
Human ecology is concerned not only with all of the above aspects of system structure, functioning, and dynamics but also with how they are affected by interactions between the social and the ecological subsystems of the human ecosystem. Rokiah Talib, in her paper, "Agricultural Land Development and Forest Clearance in Peninsular Malaysia," provides a detailed case study that reveals some of the very complex system interactions between society and nature in the course of agricultural development. Each of these system aspects is discussed in turn below in the context of agroecology.

System Structure

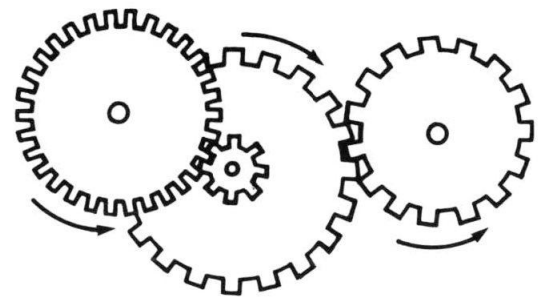
Any system is composed of two or more interacting components. When we speak of structure, we are referring to the relationships that exist between these components (Figure 2). The solar system consists of a number of bodies of differing mass in which the motion of each body is determined by the gravitational influences of all the others. A clock is a system consisting of an interlinked set of gears where the movement of one transmits energy to the next, ultimately moving the hands around the face in an orderly fashion. A living body is a system composed of a variety of organs that interact in a vast number of ways, including the pumping of blood through the arterial system by the heart. A human family constitutes a kinship system in which individuals are related to one another through their performance of roles such as father, husband, mother, and wife.

An ecosystem is an extremely complex system composed of soil, water, air, and living organisms, with all of these components structurally related through their interchanging of energy, materials, and information (Figure 3). Likewise, a human social system is composed of people, technology, social and political institutions, and ideas, beliefs, and values (Figure 4).

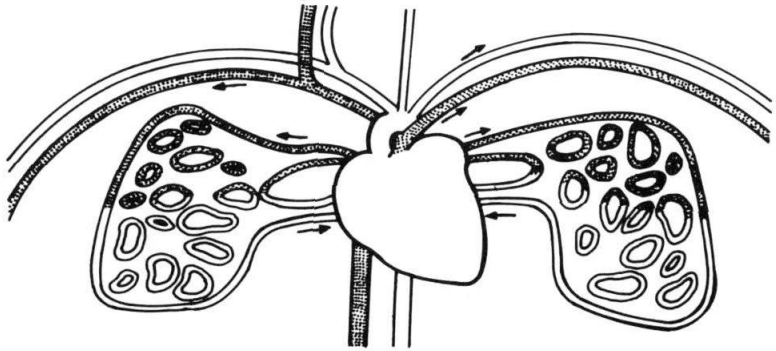
A system is not composed of a random collection of components. Instead, its elements are functionally integrated, requiring a certain "goodness of fit" if the system is to work effectively and persist over time. This does not in any way imply the existence of perfect harmony in the relationships between components. Conflict and contradiction are to be expected in natural as



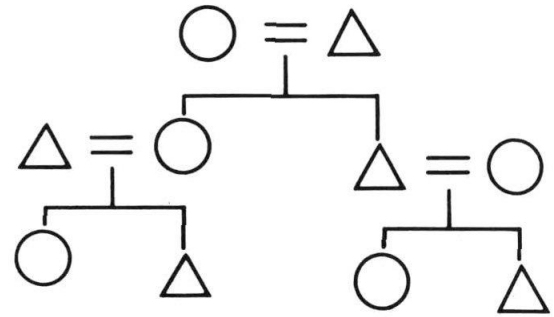
Solar system



Mechanical system



Circulatory system



Kinship system

Figure 2. Examples of systems.

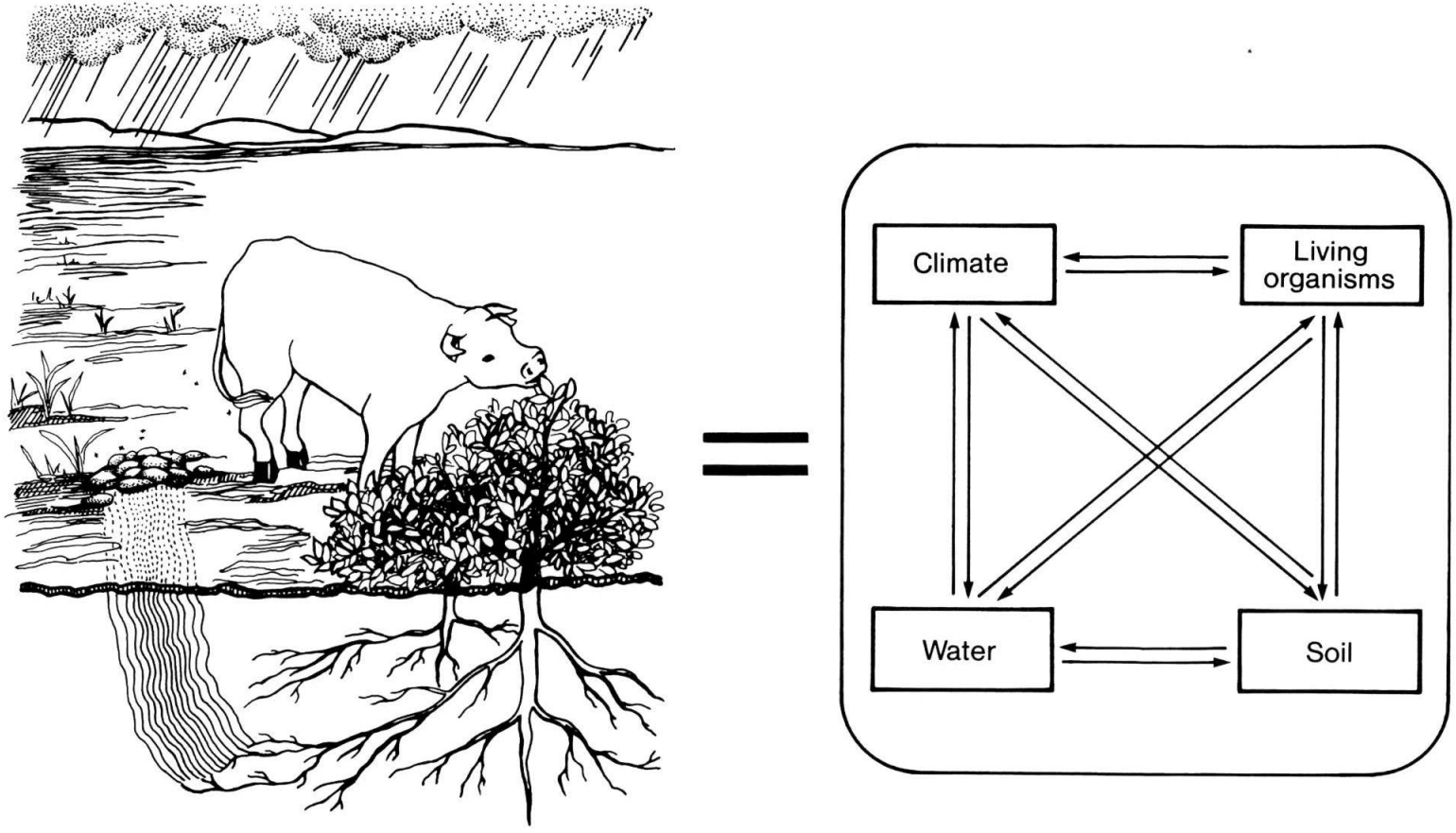


Figure 3. An ecosystem.

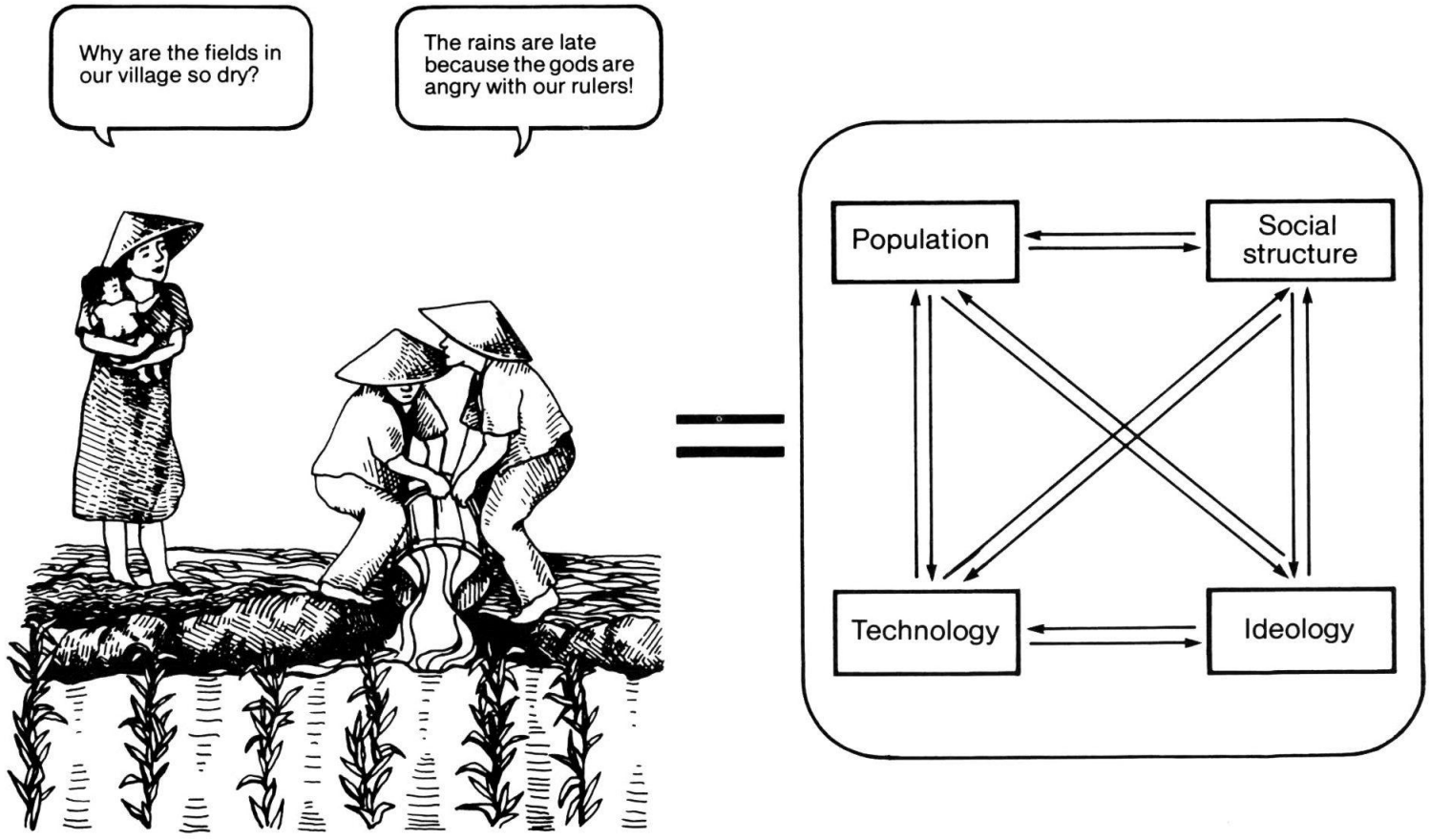


Figure 4. A human social system.

well as social systems, and it is such contradictions that provide much of the motive force for progressive change in the internal structure of systems. It does mean that in any system that has persisted for any period of time, the components are mutually adapted. Students of natural history have long recognized that the morphology of plant and animal species, for example, is compatible with climatic conditions. Thus, animals native to cold environments tend toward larger mass (Bergman's rule) and shorter extremities (Allen's rule) (both heat conserving features) than related tropical species.

Components of social systems also tend toward functional integration. One does not find elaborate class stratification in a small, nomadic, hunting and gathering society, for example. The question of functional integration of social systems is further discussed in the Workshop paper by Rambo.

The social system and the ecosystem also tend toward integration over time, with each becoming more adapted to the influences exerted by the other. In fact, it was the intuitive recognition of such adaptation that lay behind the now discredited theories of geographical determinism and possibilism, two approaches to the study of human-environment interactions that are described by Peter Pirie in his Workshop paper. It was only, however, with the adoption of the systems perspective that scientifically credible analysis of the integration of social and ecological systems began. Pirie, in his discussion of the interplay between population density, arable land and other natural resources, land tenure rules, cultural values, class conflicts, and changes in fertility behavior, suggests some of the complexities of such integration. This issue is also illustrated by Rambo in his description of the interaction between disease, land use, and cultural patterns in agroecosystems in upland areas in Indochina.

Conway describes a successfully tested method for analyzing agroecosystem structure, and Terd Charoenwatana and Manu Seetisarn provide detailed descriptions of actual agroecosystems in northeast and north Thailand respectively. Zhong Gongfu, Qin Wenging, and Huang Facheng describe the structure of the field-pond system of the Pearl River estuary, and Pei Shengji presents a brief account of the Dai agroecosystem of Xishuang Banna. Such structural description provides a necessary basis for analysis of flows of energy, material, and information within the human ecosystem, issues that will be discussed in greater detail in a later section of this essay.

Another structural feature of significance is the arrangement of systems into nested hierarchies. Social and ecological systems are mental constructs that can be applied to analysis of real-world phenomena ranging in scale from the micro to the macro level. One can take a spoonful of water from a pond, place it in a jar where it receives sunlight, and have a microecosystem with all or most of the structural attributes of any ecosystem. At the other extreme, one can view the whole of the earth as a single giant ecosystem, known in this case as the "biosphere." In between these extremes lie a whole range of ecosystems. In his paper, Conway suggests one possible hierarchy for categorizing agroecosystems in Thailand. Other hierarchies may well be appropriate for other countries or environments.

Social systems also comprise a hierarchy ranging from the nuclear family at the smallest scale to the "world system" at the global level. Again, between the extremes are a series of successively larger systems, e.g., villages, tribes, provinces, regions, nations. Conway and Seetisarn suggest hierarchies applicable to Thailand, but again it should be recognized that each country or cultural area may require its own special hierarchy. Clearly this is true in the case of China, where rural social organization involves units, such as production brigades and communes, that are uniquely Chinese.

One of the most important structural aspects of systems is that of "emergent properties." This simply means that a system is more than the sum of all its parts. It constitutes, in effect, a super organism whose behavior cannot be satisfactorily explained by looking only at each of its individual components. Conway illustrates the concept of

emergent properties with the example of the plowing system. It consists of a number of parts or elements—the plow, the buffalo, the farmer, each of which can be further subdivided into components—but it is only when these are all arranged into a certain pattern linked by certain functional interactions that the desired outputs are obtained. In this case, the emergent property of the system is the act of plowing.

Social systems also have emergent properties. A crowd of unrelated individuals will behave very differently than will the same number of individuals in an organized group, such as an army unit or a production team. Understanding how the relationships between its individual members may affect group behavior toward the environment is one of the most important contributions that social scientists can make to human ecology research. Particularly important is the issue of how the group's social organization influences its ability to manage its agroecosystem. Certainly the response of the northeastern Thai farmers, who have no effective organization above the level of the household, to the sorts of environmental stresses described by Terd Charoenwatana, is very different from what might be expected from a communal structure like that in China under the same conditions.

System Properties

Any system can be characterized in terms of having various emergent properties. Conway identifies four such properties of agroecosystems: productivity, stability, sustainability, and equitability. Productivity is the property of greatest concern in conventional agronomy but, if achieved at the cost of decreased stability and sustainability, it may be a mixed blessing. The former line that "grain is the key link" is an example of emphasizing the property of productivity to the detriment of stability and sustainability. Instead, it should be recognized that maximizing achievement of any one property may negatively affect other properties. The designer of agroecosystems must therefore always make trade-offs between different properties.

Whether "equitability" is a property of agroecosystems, as Conway believes, is a matter of debate. It may be more appropriate to consider equitability as a property of the social subsystem since it is usually determined by social and political factors such as patterns of land tenure, control of capital, and labor organization, rather than by attributes of the ecological system per se. Sugarcane, for example, can be grown equally well on plantations worked by slaves, as occurred in the Caribbean in the eighteenth century, a situation of very low equitability; by independent smallholders as in Thailand or Indonesia today, a system producing moderate equitability; or on communal farms such as the one we visited in Shunde County, a form of productive organization with very high equitability. Still, it is clearly important to recognize that changing the character of an agroecosystem may affect equitability.

Conway's list of agroecosystem properties is not exhaustive, and a number of additional properties may also be relevant. Among these are energy efficiency, economic efficiency, compatibility with other ecosystems, dependency on other systems, and cultural acceptability. Energy efficiency is measured in terms of the output of usable energy (food or fuel) compared to the input of work energy needed to make the system function. Recent research on many types of mechanized farming systems in Western countries has revealed very low levels of energy efficiency with only two to five food calories produced for each calorie expended on work. Some systems, such as feedlot raising of cattle and intensive vegetable and fruit raising, may actually operate at an energy loss. In contrast, many traditional Asian farming systems appear to be highly energy efficient, with Chinese wet rice farming said to yield as much as fifty food calories for every work calorie expended. Slash-and-burn agriculture has also been said to be highly energy efficient, with one calorie of human work yielding sixteen food calories. This calculation omits the energy value of the plant biomass consumed in burning the field, however. When this biomass energy, which performs much of the work of cultivation in swidden systems, is taken

into account the ratio is much less favorable, with at least ten work calories needed to produce one food calorie. From this standpoint, then, the very low "forest efficiency" value assigned to slash-and-burn cultivation by Zhang Jiabin in his paper appears understandable.

An important point with regard to energy efficiency as an agroecosystem property is that achieving high efficiency is not always an objective of the farmer. In situations where population density is low and forested areas are extensive (the traditional situation in southern China and Southeast Asia), for example, biomass energy is not a limiting factor in swidden farming, and there is no incentive for farmers to try to conserve energy. It is only when population pressure on the land does not permit forest regeneration that energy becomes a limiting factor and efficiency calculations like those made by Zhang take on practical significance. It should also be recognized that where the output of a system has either high nutritional value, as in the case of milk and meat, or high economic value, as in the case of the milk-fed mink raised on the Youth Associated Farm in Anhui Province discussed by Qu Zhongxiang, the fact that energy inputs may exceed the energy-value of the harvest is not necessarily a cause for concern. Nevertheless, for planning purposes, it is useful to conduct careful energy audits of different agroecosystems in order to be able to select the most efficient possible system for achieving a given development goal.

Like energy efficiency, economic efficiency is measured as an output-input ratio; in this case, cash yield compared to cash investment. For an agroecosystem to be economically viable, it must, over the long term, have a positive economic efficiency, with returns per unit of cash invested at least as high as are expected in any other potential uses of the investment capital. Benefit-cost analysis to ascertain economic efficiency is a standard feature of rural development planning in capitalist societies, and, in suitably modified form, is also increasingly employed in socialist economies as well.

Such straightforward benefit-cost analysis often ignores, however, a variety of "hidden" costs and benefits, particularly environmental goods and services to which it is difficult to assign a cash value, as is pointed out in the paper by John A. Dixon and Wang Yiting. It is easy to compute the cost of clearing one hectare of forest and planting a rice crop, and then to compare the value of the rice to cultivation costs to determine if the output value exceeds the input costs. But how does one value the topsoil lost due to increased erosion and the changes in water runoff characteristics, let alone the value of rare forest species that may be driven into extinction by destruction of their natural habitat?

These are issues addressed by Dixon and Wang and, from a somewhat different analytic perspective, Zhang Jiabin. As their contributions make clear, calculation of the economic efficiency property of an agroecosystem must take environmental residuals and externalities into account. When this is properly done, many projects that initially seem to be economically justified are actually found not to be so, with their true costs, particularly in the long run, far exceeding their short-term cash benefits. On the other hand, projects that may not appear profitable according to conventional economic analysis, may, when environmental benefits are taken into account, yield an unexpectedly high rate of return. It appears likely, for example, that processing of human nightsoil into biogas may be such a case when the public health benefits of using this technology are assigned their proper value.

The compatibility of an agroecosystem with other ecosystems is another important system property. This property refers to the off-site impacts of any particular agricultural system. Slash-and-burn-cultivation in upland areas, for example, by increasing soil erosion can cause siltation of irrigation works in the neighboring lowlands. By releasing carbon dioxide into the atmosphere, slash-and-burn can also contribute to the "greenhouse effect," which is resulting in global climatic warming. Both impacts reduce its compatibility with these other systems. Use of pesticides in rice fields may increase productivity there but will have a disastrous impact on

neighboring fish ponds. Thus, developing biological pest control as a substitute for use of chemical pesticides, as is discussed in the paper by Pu Zhelong, can make an important contribution to increasing intersystem compatibility.

The converse of the property of compatibility is that of dependency, the degree to which continued functioning of an agroecosystem may be dependent on inputs from other social or ecological systems. The high productivity of coastal estuaries depends on continuing inflow of nutrient-rich sediments from surrounding coastal zones, just as the fish ponds in the field-pond system of the Pearl River Delta described by Zhong, Qin, and Huang need a constant supply of crop residues from the fields to give high yields. In the latter case, the relationship between the pond and field ecosystems is highly compatible because the nutrient-enriched sludge from the bottom of the ponds is returned to the fields as manure for the crops. A less satisfactory relationship exists between lowland and upland areas in south China, as well as in much of Southeast Asia, where high lowland productivity is maintained by "mining" the resources of the uplands. Lowland villagers not only collect fuel and timber in the stunted forests on the highly eroded hills, but also graze their livestock there and even rake up grass and litter to carry down to fertilize their lowland fields. All movement of nutrients is in one direction—downslope—and for hundreds of years the productivity of one ecosystem, the lowland paddy field, has been maintained through the degradation of another system, the upland forest. A key research question is whether or not it is possible to increase the compatibility between lowland and upland ecosystems.

As human-managed systems, agroecosystems may also exhibit dependency on inputs from external social systems. Maintenance of the high productivity of American agriculture, for example, in which one farmer is able to produce enough food to supply fifty urban workers, is absolutely dependent on a continuous supply of petroleum. Much of this petroleum, which is needed to power the farm machinery that substitutes for expensive human labor in American farming, is imported from foreign sources, many of which are politically unstable. This creates a dependency that threatens the sustainability of American agroecosystems. The highly mechanized Guangming Animal Husbandry Farm in the Shenzhen Special Economic Zone, with its heavy reliance on foreign technology and continued need for imported animal feed, appears to display similar dependency.

Agroecosystems producing cash crops are also dependent on markets outside the control of the local social system. The farmers growing cassava in northeastern Thailand can do so profitably only as long as the European Common Market countries provide a market for cheap livestock feed. If their access to this market should be cut off, as could happen at any time, then cassava will no longer be a viable crop in the northeast, despite its demonstrated ecological suitability to the rainfed conditions prevailing there, which are described by Terd Charoenwatana in his paper. Social scientists have been particularly concerned with questions of dependency, especially in relations between developing and developed countries. Some of the ideas associated with what has come to be known as "dependency theory" are discussed by Rambo in his paper.

Cultural acceptability is a property of agroecosystems that is rarely recognized, at least explicitly, by agronomists. This property refers to the goodness of fit between management requirements and outputs of the agroecosystem on the one hand, and the capabilities, needs, and values of the human society on the other. An agroecosystem may be highly productive, stable, and sustainable, and thus "ideal" from an ecological point of view, but if it requires its human managers to engage in activities they find distasteful, or if it yields products that are not wanted by them, then it is unlikely to be adopted. For example, incorporating biogas production into the Shunde County agroecosystem has many ecological advantages, which are described in detail in the paper by Hu Binghung and Huang Zhuangbiao. Maintaining the generators, however, particularly the difficult and unpleasant task of cleaning the pits, also places time and labor

demands on the farmers that they may be unwilling to meet over the long term. As still another example of problems of cultural acceptability, the energy-efficient system of using crop residues and human nightsoil to feed pigs and then using the pig manure to feed fish, described in the paper by Zhong, Qin, and Huang, would be culturally unacceptable in Indonesia or Malaysia, where followers of the Islamic religion are forbidden to keep pigs or consume pork. In consequence, wastes must be directly fed to fish, eliminating the possibility of adding an additional trophic level into the agroecosystem and thus reducing the agroecosystem's energy efficiency. As still another example, during periods of food scarcity in the dry season in northeastern Thailand, poor farmers obtain some of their protein by eating insects that feed on buffalo dung. Such a method of producing high-quality protein from dung is ecologically sound but is not acceptable in many other places, including Western countries, where there are strong cultural taboos against eating insects (although, ironically, lobsters and crabs, which can be thought of as insects of the sea, are highly prized foods in these cultures).

Cultural acceptability as an ecosystem property is thus determined by what people have to do to manage their agroecosystem and what they get from it in return. The sum of these relations is a major aspect of their overall quality of life, a concept discussed in his Workshop paper by Joseph P. O'Reilly. As he points out, only some of the many things that contribute to quality of life can be measured objectively, while many others are highly subjective. Thus, while one can easily count the number of biogas generators in a village and record the amount of energy they yield, it is much more difficult to determine how the people actually feel about doing the work of maintaining them. Yet the argument can be made, as it was by O'Reilly, that increasing people's sense of satisfaction with life is at least as important an objective of rural development programs as is increasing the production of commodities. In fact, the most difficult balance to achieve in rural development may well be that between cultural acceptability and other agroecosystem properties. Rokiah Talib illustrates this point in her comparison of two modes of agricultural land development in Malaysia, where one mode, that of the capital-intensive federal land development schemes, produces higher economic productivity but the other mode, the labor-intensive states schemes, results in greater social integration. Such trade-offs between system properties pose difficult choices, and different countries will make different decisions depending on their national priorities.

System Functioning

The components of social and ecological systems are functionally related through the exchange of energy, materials, and information. Such flows also articulate these subsystems into the human ecological system. Thus, analysis of the flow of energy, materials, and information is a key area of human ecology research and is a fundamental basis for understanding agroecosystems. Each of these flows is discussed here in relation to agroecosystem functioning.

Energy flow. In simplest terms, energy may be defined as the ability to do work. It is the energy stored in plant and animal foods that powers human muscles and the energy stored in gasoline that powers internal combustion engines. Until the discovery of nuclear energy, almost all energy used by humans was either directly or indirectly derived from the sun and even today by far the largest share of energy is of solar origin.

American anthropologist Leslie White has suggested that human social evolution reflects the increasing ability of societies to capture and efficiently use energy from the environment. According to White, primitive hunting and gathering societies had available only the very limited energy supplied by human muscle power (i.e., one-sixth of a horsepower per capita). More advanced agrarian societies, using animal, wind, and water power, may control the equivalent of several horsepower per capita; but industrialized societies, using fossil fuel-powered machinery,

control several hundred or even thousand horsepower per capita. Empirically, there is a close correlation between the level of energy use and GNP, so that those countries with very low per capita rates of energy expenditure (e.g., Bangladesh, Haiti, Chad) are also characterized by very low per capita incomes. Thus, a key problem in the developing countries is to increase the supply of energy, particularly in the rural sector.

In view of the high cost and limited availability of fossil fuels, it is clear that developing countries will have to make maximum possible use of alternative energy sources. It is in this light that Professor Qu Zhongxiang's paper setting forth his tentative plan for the development of ecological farms is of such significance. According to Professor Qu, a major goal in ecological farming is to raise the transformation rate of solar energy into biological energy and then to employ this supply of biological energy in the most efficient possible ways to support agricultural production.

One way to achieve this goal is to breed crops that will capture solar energy more efficiently. As Professor Qu points out, "The utilization rate of light energy for wild plants at present only amounts on the average to 0.5 percent; the rate for grain crops 0.5 to 1 percent; and that for high-yielding crops remains a low level of 1.5 to 2 percent. . . ." According to Professor Qu, spring wheat that reaches a maximum efficiency during its growing period of 5.9 percent has been developed in Qinghai Province. Such "microcosmic genetic engineering," as Professor Qu labels it, obviously can make a considerable contribution toward efforts to increase energy flow rates in agroecosystems and certainly merits additional research effort.

More likely to provide immediate returns, however, is what Professor Qu calls "macroscopic ecosystem engineering," which is the manipulation of the agricultural ecosystem as a whole to increase the efficiency with which it traps and utilizes available solar energy. Such engineering involves two aspects: (1)increasing the percentage of solar energy per unit of surface area that is captured by primary producers, and (2) making maximum possible use of this energy as it moves through the trophic structure.

Altering the composition and structure of the plant community is one practical way to ensure a higher capture rate of the solar energy reaching a particular unit of surface area, both on a daily basis and over the course of the full annual crop cycle. Spring wheat, for example, although achieving an energy capture efficiency of 5.9 percent during its growing season, would display a much lower efficiency if calculated over the course of the whole year since for much of the time the ground surface is either bare or only partially covered by the young plants. This is inherently inefficient since only solar radiation that is intercepted by living leaves can be converted into biomass. The multispecies, perennial-dominated homegarden agroecosystems of Southeast Asia are one highly successful strategy for ensuring maximum possible utilization of solar radiation available on a unit-space and a unit-time basis.

A typical Southeast Asian homegarden, such as the tree-based systems of Java studied by Professor Otto Soemarwoto and his colleagues at the Institute of Ecology in Bandung, Indonesia, is a complex artificial forest community. As many as eighty useful species are interplanted to form a multistoried canopy with a leaf area index of 2.5 to 3, giving maximum interception of light per unit of ground area. Because most of the upper- and middle-layer plants are evergreen perennials, with annuals largely confined to the ground surface and understory, the leaf area index remains high throughout the annual cycle with no unproductive period when the surface is bare.

Some use of the multilayered community approach is made in China, as in the case of planting sweet potatoes beneath the pear trees in the hillslope orchards we observed on No. 2 State Farm near Kunming, and the rubber-devil pepper and rubber-tea "artificial" plant communities of Yunnan, described by Long Yiming and Zhang Jiahe, which are deliberately designed to mimic the multilayered structure of the rainforest. It is interesting to note that the research of Long and Zhang indicates that the yield from the rubber trees is actually higher when they are interplanted with pepper or tea than it is in

monocultural stands, while the farmers also gain additional economic benefits from the production of the understory crops that utilize solar radiation that would otherwise be wasted.

A second way to increase the efficiency of energy use in the agroecosystem is to ensure that maximum possible use of available net primary production is made by other levels in the trophic structure so that energy wasted by organisms at one level is channeled to other organisms able to utilize it effectively. China has a long and rich experience in this field, and there is clearly much that the rest of the world can learn from this experience.

The complex field-pond agroecosystem of Shunde County, which we observed during the Workshop and which is described in a number of the papers by our Chinese colleagues, offers a superb example of this strategy of energy utilization. A diagram in the paper by Zhong Gongfu, Qin Wenging, and Huang Facheng showed land-water interactions of the field-pond ecosystem and traced the flow of energy from producers (rice, sugarcane) to human consumers to pigs to fish.

Introduction of marsh gas or methane biogas generators, as described in the papers by Hu Binghung and Huang Zhuangbiao, can be seen as an attempt to fit an additional trophic level into the system, in this case an artificial one, but still in accordance with the basic principle set forth by Professor Qu. As Hu and Huang point out, "Traditionally large quantities of crop stalks were burned as fuel . . . only part of the energy was used while large quantities of fertilizer were wasted, and animals did not have enough fodder. On the other hand, when [the stalks] were directly applied to the fields as fertilizer, their energy was wasted. . . . Developing marsh gas is an effective way to make full use of energy and other resources."

Although employing farm wastes to generate marsh gas certainly extracts additional energy for human use from the ecosystem and also confers a number of other ecological benefits (e.g., destruction of disease organisms), it is not a cost-less process. The energy it provides is produced through the breakdown of organic material and consequently there must be some loss of bulk organic materials for manuring the fields. Of course, such a loss is preferable to the total loss of organic materials caused by burning crop residues as fuel. A perhaps more important cost, and one that is not examined in the Chinese papers, is the human labor needed to construct and maintain the biogas system. The economic opportunity costs of diversion of scarce technological and capital resources into construction of devices capable of at best meeting only 50 percent of rural energy needs also deserve further consideration.

It is not surprising that human labor as an aspect of energy flow in agroecosystems is generally not taken into account in the Chinese papers because China's very high rural population densities and socialist system of labor organization reduce the likelihood of human energy becoming a limiting factor in agroecosystem development. It does, however, raise real questions about the applicability of Chinese solutions to Southeast Asian countries with lower population densities and less well-articulated means of mobilizing available labor supplies.

Lack of concern with human labor requirements may help to explain the general antipathy of the Chinese to slash-and-burn shifting cultivation as a means of agricultural production. With the partial exception of Pei Shengji, who has studied shifting cultivation as practiced under conditions of low population density by minority peoples in Xishuang Banna, the Chinese Workshop participants unanimously viewed slash-and-burn farming as a bad system that should be replaced immediately with permanent field systems of cultivation. Zhang Jiabin, for example, stated that slash-and-burn cultivation yields little economic value in comparison with other forest functions and therefore should be abolished. Wang Huihai, Ma Weijun, Deng Shunzhang, and Li Dehou further argued that shifting cultivation causes extremely serious soil erosion under tropical conditions and therefore should be replaced with the use of terraced fields.

Granting the correctness of this assessment of shifting cultivation as economically inefficient and ecologically destructive, the question that needs to be asked is, "Why do shifting cultivators

keep shifting?" In view of Pei's report on the very sophisticated knowledge that the Dai and other national minority groups in Yunnan have of their environment, it cannot be argued plausibly that they do so out of ignorance of the consequences of their activity. Nor can it be because they lack knowledge of alternative methods of agriculture, since the Dai have for centuries successfully engaged in wet rice farming in terraced valley fields. A more likely explanation is that shifting cultivators retain this system because it meets their subsistence needs with a minimal demand for human labor. This is because much of the work in slash-and-burn cultivation is done by fire using the energy stored in the forest biomass. Burning not only clears the field, releasing nutrients in the form of ash to fertilize the crops (what Zhang Jiabin referred to in his paper as the "fertilizer-yielding efficiency" of the forest), but it also alters the soil structure to make it softer and more friable, and, most important of all, sterilizes it to kill off pests and weeds. All of these functions, which are performed for the cultivator for free by burning biomass energy in shifting cultivation, must be done with human labor in other more stable forms of agriculture. In hilly upland areas, such as characterize much of south China and Southeast Asia, ecologically more stable systems for producing food crops may require vastly greater human labor inputs than the shifting cultivation systems they are intended to replace. This is especially true of the sorts of hillslope terracing advocated by Wang, Ma, Deng, and Li. More cost-effective in energy terms is the establishment of "artificial plant communities" based on interplanted perennial crops such as the rubber-devil pepper and rubber-tea associations described by Long Yiming and Zhang Jiahe and the village gardens of the Dai people described by Pei. The principal limitation of such "agroforestry systems," as they are often called, is that they have a low yield of carbohydrates needed to meet energy requirements in the human diet. Further research on how to increase production of staple foods in such ecologically desirable agroecosystems is needed if they are to replace shifting cultivation successfully.

This discussion of shifting cultivation demonstrates the value of human ecology as a framework for research on agroecosystems. It is not sufficient to understand only the physical and biological aspects of an ecosystem; it is also necessary to take the needs and capabilities of the farmers into account. Only when an agroecosystem is matched both to biophysical conditions and to social and cultural realities is it likely to win complete acceptance by the rural population.

Material flow. Often referred to in ecology texts as "nutrient cycling," material flow refers to the transfer of chemical elements and compounds between the components of an ecosystem. Carbon, for example, flows from the atmosphere into the leaves of green plants where it is fixed through the process of photosynthesis into sugars and starches. In this form it may be consumed by animals, metabolized, and returned to the atmosphere in the form of carbon dioxide gas, only to again be absorbed by plants. Alternatively, the carbon in the plants that die may be trapped under sediments and over geological time be converted into coal. Eons after it was removed from the atmosphere, this carbon may be used to fuel coal-burning machinery only to be again freed into the air. It is because materials, unlike energy, have the potential for endless reuse that ecologists often distinguish material cycling from energy flow. In human ecology, however, this distinction is less sharp, since the movement of many materials through the human ecosystem must be viewed as irreversible within time spans meaningful for human existence. Thus topsoil that is washed from unterraced hillslope fields into rivers and then carried to the sea may be in millions of years once more elevated in the process of mountain building. From the farmer's viewpoint, however, soil carried away by erosion is gone forever.

Material flows of major concern in the analysis of agroecosystems include nutrients (e.g., nitrogen, phosphorous), soil, water, and toxic substances.

Nutrients. Growth of all living organisms, including people, is dependent on an adequate supply of macro- and micronutrients. In natural

ecosystems, supply and demand for nutrients are generally in equilibrium. The nutrient cycle between the soil and living organisms is essentially a closed one, with losses due to leaching and runoff made good by inputs from the atmosphere and decomposition of parent material. Agroecosystems, however, are rarely closed systems and there is constant export of nutrients from the fields into human settlement areas. Such "fertility migration," as it has been called, has been occurring for thousands of years in cultivated regions of Asia, including China. A major objective in Chinese ecological farming is to re-close the cycle so that nutrients extracted from the fields in the harvest are subsequently returned to maintain high plant productivity.

Chinese agriculture has a long tradition of recycling nutrients. Particularly impressive is the well-developed system of collecting nightsoil in urban centers and returning it as manure to the fields in the surrounding countryside. Recycling animal wastes and crop residues is also a highly developed system.

Several Chinese Workshop papers were concerned with ensuring that nutrients flow through the trophic structure in ways that guarantee their maximum utilization. Professor Qu refers to this as "raising the transformation efficiency . . . from nitrogenous resources to high quality protein. . . ." An excellent example of this approach is provided by the field-pond system described in the paper by Zhong, Qin, and Huang. In this system nutrients flow from mulberry trees to silkworms. The droppings of the silkworms, along with pig dung and the residues of sugarcane, are fed to fish. Sludge from the fish ponds, enriched with fish droppings, is in turn used as manure for mulberry and sugarcane fields, so that a closed cycle appears to have been established.

The system is not really a fully closed one, however, because the silk, sugar, and fish are mainly exported rather than consumed by the local human population. Instead, most of the harvest is exported to other areas in China and even abroad. Thus, there is a continuous large-scale flow of nutrients out of the local agroecosystem. Unless ways are found to make good this continuous outflow, such as may be done through application of chemical fertilizers, the local agroecosystem is bound to suffer degradation of its productivity over time.

Of the major nutrients, nitrogen may be the simplest to replace since it can be captured from the atmostphere by nitrogen-fixing bacteria associated with leguminous plants, casuarina, blue-green algae, and azolla. In this regard it is significant that the tree strips in the "farmland forest network" described in the paper by Liu Jihan include *Casuarina equisetifolia L.* and *Leucaena leucocephala,* a nitrogen-fixing tree of Central American origin. *Leucaena* is also being used with considerable success for agroforestry in Indonesia and the Philippines. Along with providing fodder for livestock, it is useful for green manure. Percy Sajise, in his paper on upland management research in the Philippines, reported on experiments being conducted there using *Leucaena* to rehabilitate nutrient-depleted soils.

Less tractable than the problem of replacing nitrogen is that of replacing lost phosphorous and potassium, among the macronutrients, as well as the many micronutrients that can become limiting under intensive cropping systems. Once removed, there is no way to regenerate these nutrients locally although, as Sajise described, inoculation of plant roots with certain mycorrhiza can enhance their ability to utilize scarce supplies of phosphorous. In future analysis of Chinese ecological farms, it may be suggested that all inflows and outflows of nutrients be assessed rather than assuming that the system is a "closed ecological cycle" simply because manure and crop wastes are being recycled, as is asserted with the Kunming No. 2 State Farm.

As in crop plants and livestock, human well-being is also dependent on maintaining an adequate nutritional level. A major concern in agricultural development is thus to ensure that human consumers receive an adequate supply of calories, sufficient high-quality protein, plus essential vitamins and minerals. The integrated field-fish pond system developed in Shunde County is clearly an efficient means of achieving this end, since materials that would otherwise be wasted are used to produce fish. It is less obvious that dairy farming

of the sort practiced at Kunming No. 2 State Farm and the Guangming Animal Husbandry Farm that we observed in Shenzhen are ecologically rational (however great their economic justification), since the cattle directly compete with people for food. Certainly, the use of meat and milk to feed mink on the Youth Associated Farm in Anhui Province as reported by Professor Qu would appear to deserve further consideration from this perspective.

Soil. Soil erosion is a major concern in the humid tropics. As the paper by Wang Huihai and his colleagues at the Research Institute of Tropical Botany of Yunnan Province showed, rainforest clearance in mountainous regions leads to massive soil erosion. They reported that the loss of soil from agricultural fields on slopes in one year equaled the loss from forest in more than 600 years! Terracing, one of the solutions they recommended, is only partially effective and has great cost in human labor. Use of strips of *Leucaena* planted along the contour, as described by Sajise, may be a more cost-effective way of achieving the same degree of erosion control. Far more effective, however, is planting "multilayered, multispecies economic forest," which according to Wang and colleagues has 95 percent less erosion than farm fields and involves a much lower human labor input than terracing. This solution is also advocated by Long and Zhang.

Soil erosion, although usually lowering the productivity of the originating ecosystem, is not always a wholly negative phenomenon from the standpoint of overall agricultural production. The ability of Egypt to produce crops continuously over several thousands of years, for example, is explained by the continuous deposition of new fertile sediments by the annual floods of the Nile River. These sediments originate in the highlands of Ethiopia, reflecting disturbance of the soil community there by slash-and-burn cultivation and overgrazing dating back to Neolithic times. Similarly, George Lovelace has shown that creation of new lowland rice fields in south China was accelerated by deposition of sediments eroded from hill slopes cleared for grave sites in accordance with the precepts of *Fengshui* (geomancy). From our observations in Yunnan, it is evident that the hill soils continue to be mined to help maintain productivity in the irrigated flatland fields. A question that needs to be addressed is, "What would be the impact of truly effective erosion control throughout the uplands on lowland production?"

Water. The hydrological cycle is a classic example in ecology textbooks of the endless recycling of materials through the biosphere. At the farm or local agroecosystem level, however, movement of water through the system, like that of soil, is better seen as a flow rather than a cycle.

A major concern in a number of the Chinese-authored papers is the role of vegetation in controlling the flow of rainwater runoff from upland to lowland areas. Professor Qu stressed the great value of forests in conserving water and called for vigorous efforts to raise the low percentage of forest cover in China. His assertions were provided empirical support by Zhang Jiabin, who showed that undisturbed forest in Yunnan can absorb more rainfall than actually falls. Consequently, flooding historically was not a threat but has become a major danger in the past decade due to the reduction in forest coverage. Zhang calculates the economic benefit provided by the forest in conserving water as equivalent to 142 *yuan* per *mu*, on the basis that construction of engineering works to store an equivalent volume of water would cost at least that much. While the method of calculation is probably too simplistic, omitting questions of opportunity cost, interest and discount rates, and depreciation, it still serves to illustrate the important contribution that vegetation plays in controlling the flow of water, a contribution that has demonstrable economic value.

While keeping land under forest may be best for water conservation, growing human needs for food and fuel require that natural forests be converted to other uses. It is, therefore, of great importance to assess, as Wang Huihai and his colleagues did in their paper, the impact that various alternative land uses have on runoff. Their work shows that while clearing agricultural fields on slopes greatly increases runoff, substitution of economic agroforests for natural forests has rela-

tively minor impact. Runoff from a multilayered rubber-tea community is only 2.1 times higher than from natural forest, whereas a farm field produces 34.5 times more runoff. Terraced fields, although performing better than unterraced ones, still have 6 times more runoff than forests.

In rainfed farming, such as Terd Charoenwatana described for northeast Thailand, a major concern is to maximize crop use of seasonally limited rainwater supplies. Modification of cropping systems to fit a second crop into the short growing season is one promising strategy, although as Terd indicated, some ecologically feasible approaches may nevertheless be unacceptable to the farmers because of low and uncertain economic returns and increased labor demands that conflict with other priorities in the agricultural cycle.

Toxic substances. Everywhere in the world, development is accompanied by the increased discharge of potentially harmful substances into the environment. Use of chemical pesticides in agricultural activities is a major pollution source and poses a growing threat to ecosystem stability and human health.

As Pu Zhelong discusses in his paper, biological control of pests is one way to reduce the use of toxic chemicals. Measures include introduction of new predators on pests, conservation of existing enemies, and modification of habitats to make them less favorable to the pests and more favorable to their predators. For example, thistles are grown in citrus orchards not only to provide food for beneficial predaceous mites but also to provide these predators with a more favorable habitat by increasing the relative humidity. Artificial nests are placed in trees to attract entomophagous birds to nest in forests, thus helping to control insect pests. Locust breeding sites are reduced by transforming dry fields into flooded paddy fields. In his paper, Sajise reported that mechanical lodging of *Imperata* grass, while less effective than use of herbicides, is a much less expensive and nonpolluting means of weed control.

Use of biological controls, while reducing the need for toxic chemicals, may have unanticipated ecological consequences. For example, the use of ducks in paddy fields to control insects may adversely affect human health in situations where untreated human nightsoil is being used as fertilizer. Recent work by Professor K. F. Shortridge of Hong Kong University suggests that ducks in south China may serve as a reservoir for influenza. Infection passes from the human population to the fowl population via nightsoil discharges into the paddy fields and then from the ducks back to the human populations. Ensuring that all nightsoil is processed through biogas digesters, which sterilizes the manure before it is used in the fields, may thus have extremely important health implications, not just for Chinese farmers, but also for the entire global population.

Information flow. Information flow is the least understood of the functional aspects of ecology. Information is any sign or indicator about the state of the ecosystem or its components. It plays a particularly important role in human ecology because our behavior toward the environment is strongly influenced by the nature of our perceptions of it. In his paper, Rambo described how traditional Vietnamese peasants refused to settle in the highlands because they believed them to be the abode of evil spirits who would cause human transgressors to die of fever. Of course, we no longer accept such a supernatural explanation, but the important point is that the Vietnamese interpreted certain environmental information (dying of malarial fever) as evidence of the presence of hostile spirits and acted appropriately within the context of their traditional belief system. In fact, given their lack of technological defenses against malarial infection, their beliefs were adaptive in that they restrained people from settling in the mountains where they would almost certainly have been killed by malaria. As is very often the case, traditional beliefs may lead people to do the right thing for what, from the scientific point of view, may be erroneous reasons.

The character of human belief systems and how they influence interpretation of environmental information and consequently modify human behavior toward ecosystems is discussed in some

detail in George Lovelace's paper, "Cultural Beliefs and the Management of Agroecosystems." As Lovelace pointed out, knowledge of traditional belief systems is of more than esoteric interest to ethnologists; it can directly contribute to scientific research on human ecology. As he says, ". . . traditional beliefs contain potentially vast quantities of empirical information related to environmental phenomena, process, and historic change . . . [so that] . . . these traditional systems of knowledge can provide information useful to the planning and process of development." That this potential is real is demonstrated by Pei Shengji's work on the ethnobotany of the Dai national minority of Xishuang Banna. Information on native plants and their uses collected from this traditional society has contributed to scientific identification of some hundreds of new useful species, many of which have already been put into production. One wonders how long it would have taken Pei and his colleagues to have reached this goal without the guidance provided by the Dai people's traditional knowledge.

It should be emphasized that it is not only humans that respond to information flow. Many if not all living organisms have some capability to collect environmental information and modify their behavior in response to it. Understanding this fact can have great significance for agroecosystem research. For example, insect pests have to locate the crop plants on which they prey and may take advantage of visual and chemical clues emitted by these plants in their search for a suitable host. Use of different planting patterns, such as random intercropping, may make it more difficult for them to locate their targets while genetic modification of plant chemical emissions might make their task of recognition more difficult. The possibilities for manipulating information flow within the agroecosystem to work to the advantage of the farmers are endless but, as yet, little explored.

System Dynamics

Human ecological systems are never static or unchanging for an extended time. Instead, they are in constant flux reflecting the continuous interaction and adjustment between their social and ecological subsystems, as well as their response to pressures exerted by the larger environment. Such change over time in system structure and functioning can be divided conveniently into two categories: succession and evolution.

Succession refers to the progressive development of a system through a series of stages from immature to mature form. The concept was originally developed to describe the development of plant communities. It was observed that, starting from bare ground, the plant community in any given environment passed through a fixed set of stages—first, annual grasses and herbs, followed by perennial shrubs, which were in turn replaced by fast-growing softwood trees, which survived only until shaded out by the slower-growing hardwood trees of the climax forest community. The stages and the climax might differ depending on specific local climatic and edaphic factors so that the successional pattern or *sere,* as it is technically called, will differ in the desert and the Arctic; but within any particular type of environment, the natural succession is restricted to one or, at most, a very few *seres.*

Social systems also undergo succession. A pioneer community sent into an uninhabited frontier area will display in the beginning different structural characteristics from those typical of its home area, but over time it will develop in similar directions. The southward spread of the Han Chinese and the westward migration of American pioneers offer two well-known examples of social succession.

Succession is a key concept for the analysis of agroecosystems. Agriculture can be seen as the deliberate manipulation of successional patterns to maintain a community in an early successional stage when net productivity is high. This is particularly evident in the case of the cultivation of annual grains and vegetables where the plot is cleared to bare ground before the desired crops are planted. It is thus not surprising that most cultivated annual crop species are derived from wild species adapted to early successional stages. Such species frequently follow an "r-strategy" in

their population dynamics, being short-lived individuals that invest most of their energy in producing large numbers of progeny. It is these progeny, in the form of seeds, fruits, or tubers, that are exploited as food by humans. In contrast, "K-strategy" species, the long-lived perennials of the climax community, invest relatively less energy in reproduction and, hence, do not yield large quantities of human food.

Maintaining an agroecosystem in an early successional stage is difficult precisely because it means blocking the normal progression toward the climax stage of the *sere*. Without continuing human intervention, any field will eventually revert to forest, a natural process that is the basis for the successful conduct of slash-and-burn cultivation. In fixed-field agriculture, however, such succession is undesirable, and considerable quantities of human labor must be expended to prevent its occurrence. This is particularly demanding in the humid tropics where succession is much more rapid than it is under temperate conditions.

One solution is an agroecosystem based upon perennial tree crops such as tea, rubber, or fruits. Such species, because they are characteristic of a later successional stage than annuals, are much easier to maintain as a relatively stable community, what Long Yiming and Zhang Jiahe referred to in their Workshop paper as an "artificial plant community."

In contrast to succession, evolutionary change does not move through a set of fixed stages. Instead it is a stochastic process in which the outcome of each selection event establishes the conditions for future changes. There is, therefore, no reliable way to predict what will happen before it occurs, although it is possible to explain the nature of events after their occurrence. It may also be possible to derive certain general trends or principles from history that can be expected to continue into the future. The progressive emergence of ever-larger and more complex living systems may be one such trend.

Above all else, however, study of evolutionary history reveals the value of diversity in giving a system the ability to adapt to changing conditions. An attribute having no evident value under present conditions may prove extremely useful in future environmental perturbations. This has the implication that in designing improved agroecosystems emphasis should be placed on maximizing local experimentation and innovation rather than imposing a single uniform model. The uniform model may be more productive in the short run under stable conditions, but it exposes the system to the possibility of total disaster if conditions suddenly change in unexpected ways. In contrast, a diversity of local systems offers the possibility that at least some will be able to survive under new selective forces. What is true of ecosystems also appears to be true of social systems, so there is likely to be survival advantage in maintaining maximum cultural diversity compatible with the needs of national integration. China's policy of granting considerable autonomy to national minorities appears worth examining from this viewpoint.

Human ecology, on the whole, has paid little attention to questions of evolution. Most studies have been synchronic ones, describing the adaptation of social systems and ecosystems at a single moment in time rather than seeking to explain the processes leading to such adaptation. In dealing with issues of agricultural development, however, it is clearly necessary to pay great attention to the nature of ecological and social change. One central question, addressed in the paper by Peter Pirie, is that of the relationship between changing agricultural technology and human fertility behavior. A number of theories have been advanced in this regard, most notably Boserup's hypothesis that population increase causes agricultural intensification but, as Pirie observes, none is a fully satisfactory explanation of the complex process.

If human ecology is to make a contribution to rural development policy, it must confront the questions of how and why systems change. This requires us to develop a far more sophisticated understanding of evolutionary processes, particularly those affecting social change, than we now possess. As pointed out in the paper by Rambo, however, existing social science theories are less

than wholly satisfactory in their ability to explain change. Recognition of the dialectical relationship between society and the environment, as is explicit in the systems model of human ecology, opens a new perspective on the problem of system dynamics and holds the promise of our being able to integrate knowledge derived from both ecological and social science research into a single coherent strategy for development of the human ecosystem. The papers presented in this Workshop show that we have already made considerable progress toward this objective, but they also reveal that there is still much to be done. In particular, there is still a long way to go in bringing natural and social scientists together, both intellectually and institutionally, so that they can employ the human ecology perspective effectively in their research.

Data collected by scientists working in many different disciplines can be integrated into a single unified perspective provided by human ecology. Employment of the concepts of system structure, functioning, and dynamics has permitted the analysis within a common framework of issues as seemingly diverse and unrelated as soil erosion, use of wastes to generate marsh gas, biological control of insects, human labor demands, rural social organization, and changes in human fertility behavior. Doing this is important, not as an academic exercise but as a way of bringing the organization of applied scientific research into conformity with rural realities. As Gordon Conway points out, farmers do not operate in a world divided neatly into disciplinary compartments. Instead, they simultaneously respond to physical, biological, and social imperatives of the agroecosystem of which they are a part. The problems to be solved in rural development, therefore, are not exclusively those of physics, chemistry, biology, or agronomy, on the one hand; or anthropology, economics, geography, or psychology, on the other. Rather, they are systemic in nature and involve complex interactions between biophysical and social factors, and they fall outside the boundaries of any single discipline's area of concern. Because it is a broad perspective rather than simply another discipline, human ecology offers a way to organize research to better conform to the structure of the "farmer's world." This is not to argue for the abandonment of disciplinary-based expertise. Given the complexity of agroecological research problems, such expertise is needed more than ever before. Such specialized research should be conducted within a framework that allows its results to be integrated with other data into a coherent synthesis appropriate for rural development planning.

Workshop Follow-Up

The question that now needs to be addressed is, How can we move beyond such general programmatic statements about the desirability of human ecology research into actually doing it to produce useful results? More specifically, what steps might EAPI and the scientists in the Southeast Asian Universities Agroecosystem Network (SUAN) and China take to develop future collaborative activities to promote human ecology research on agricultural systems?

The first step, and something begun at this Workshop, is to exchange information about our research activities. The breadth and sophistication of the agroecological research being carried out by our Chinese colleagues makes it evident that we share many concerns and are employing similar methods in our research on these rural development issues. It is hoped that Chinese scientists will be able to participate in future joint EAPI/SUAN conferences and workshops. In fact, one Chinese participant in our Workshop has already attended a conference on cultural values and tropical ecology held at the East-West Center in June 1983, with several Southeast Asian scholars also taking part.

The second step would be to organize joint research workshops focused on specific issues of common interest. EAPI participants suggested four basic criteria that could be employed in selecting problem areas to be dealt with in future joint activities:

- Research should contribute to better management of hilly areas, particularly degraded uplands. Especially needed is an analysis of interactions between upland and lowland

agroecosystems, since it is evident that the problems of the uplands cannot be solved without understanding the demand for resources that is placed on them by lowland systems.

- Research should involve making a comparative analysis of the structure, functioning, and dynamics of a variety of different agroecosystems. Systems in different ecological regions in southern China might be compared, as might a traditional "closed" subsistence system such as that of the Dai of Xishuang Banna, with an "open," commercially oriented system such as the Kunming No. 2 State Farm.
- A common human ecology conceptual framework should be employed, permitting the integration of research by natural and social scientists. It might be fruitful to organize a joint interdisciplinary research team in which Chinese scientists representing a range of natural and social science disciplines are paired with counterparts from EAPI/SUAN.
- Tropical and subtropical agroecosystems in southern China, particularly those of Yunnan Province, should be given priority due to their greater similarity to the types of systems already being studied by SUAN research teams and EAPI.

Understanding rural development is an immense intellectual undertaking requiring all of the scientific resources that can be mobilized, in both developed and developing countries. There should be no leaders and no followers; all should participate to the maximum of their abilities. The advances in understanding agroecosystems already made by the SUAN research teams, as represented in several of the papers presented in this Workshop, indicate the results that can be achieved when scientists, regardless of disciplinary affiliation or nationality, choose to work together as equal partners in human ecology research. Based on our experience in this Workshop, we know that Chinese scientists can make major contributions to our collaborative work and we intend to seek opportunities to make this possible.

SYNOPSES OF WORKSHOP PAPERS

List of Papers Presented

Papers presented by the Chinese participants:

1. Qu Zhongxiang, Yunnan University
   Introductory Paper: "A Tentative Plan for the Development of Ecological Farms in China"
2. Hu Binghung and Huang Zhuangbiao, Marsh Gas Research Institute, Guangdong
   "Application of Marsh Gas as an Energy Resource in Developing Agri-Ecological Systems"
3. Liu Jihan, Farmland Forest Research Network, Guangdong
   "A Preliminary Observation on the Creation of the Farmland Forest Network and Its Effects in Doumen County in the Pearl River Delta"
4. Long Yiming and Zhang Jiahe, Research Institute of Tropical Botany, Yunnan
   "Ecological Effects and Economic Results of the Artificial Plant Community"
5. Pei Shengji, Research Institute of Tropical Botany, Yunnan
   "A Preliminary Study of Ethnobotany in Xishuang Banna"

6. Pu Zhelong, Research Institute of Entomology, Zhongshan University, Guangdong
   "The Biological Control of Insect Pests and Insect Pest Management in China"
7. Wang Huihai, Ma Weijun, Deng Shunzhang, and Li Dehou, Research Institute of Tropical Botany, Yunnan
   "The Correlation Between the Exploitation of the Tropical Forest in Southern Yunnan and the Water and Soil Conservation"
8. Zhang Jiabin, Fourth Forest Resource Prospecting Team, Yunnan
   "A Study of the Basic Theory and Technical Methods to Assess the Efficiency System of Forests"
9. Zhong Gongfu, Qin Wenging, and Huang Facheng, Guangzhou Institute of Geography, Guangdong
   "The Ecological Patterns in the Field-Pond System of the Low Lying Sandy Land of Both Sides of the Zhujiang (Pearl River) Estuary"

Papers presented by the EAPI-sponsored participants:

1. A. Terry Rambo, East-West EAPI
   Introductory Paper: "Ecosystem Models for Development: An Introduction to Human Ecology as a Methodology for Development Research, Planning, and Analysis"
2. Terd Charoenwatana, Khon Kaen University, Thailand
   "Agricultural Ecology Research in Northeast Thailand: The Rainfed Cropping Systems"
3. Gordon R. Conway, Imperial College, London
   "Identifying Key Questions for the Development of Ecosystems"
4. John A. Dixon, East-West EAPI, and Wang Yiting, Chinese Research Academy of Environmental Sciences
   "Using Benefit-Cost Analysis to Evaluate Alternative Strategies for Developing Tropical Ecosystems"
5. George W. Lovelace, East-West EAPI
   "Cultural Beliefs and the Management of Agroecosystems"
6. Joseph P. O'Reilly, University of Hawaii
   "Agricultural Development and Quality of Life"
7. Peter Pirie, East-West Population Institute
   "Population Dynamics, Agroecosystems, and Agricultural Innovation"
8. Rokiah Talib, Universiti Malaya, Kuala Lumpur, Malaysia
   "Agricultural Land Development and Forest Clearance in Peninsular Malaysia"
9. Percy E. Sajise, University of the Philippines at Los Baños, Philippines
   "Ecological Approaches to Managing Degraded Uplands in the Philippines"
10. Manu Seetisarn, Chiang Mai University, Thailand
    "Systems Analysis of Agriculture in the Chiang Mai Valley"

Paper Summaries

A Tentative Plan for the Development of Ecological Farms in China,
by Qu Zhongxiang

An ecological farm is one that is established in accordance with the theory of ecology and, by applying ecological principles, is able to exploit, utilize, and administer natural resources in line with local conditions. A key component is the adoption of various techniques to raise the transformation rate of solar energy and to actively recycle waste products. In this way many different goals are met at the same time—total productivity is increased and the environment is protected as pollution is decreased.

Several tasks of ecological farms are outlined. The foremost task is increasing the transformation rate of solar energy by agriculture and forestry. This leads to increased productivity per unit area. Other tasks include the efficient recycling of wastes, the development of on-farm processing industries, and the development of the

exchange of goods and services between urban and rural areas. For example, municipal sewage can be used as fertilizer on ecological farms, thereby reducing urban pollutants and increasing food production.

Examples of both historical and newly developed ecological farm systems are given: the field-pond system in south China, traditional patterns in Xishuang Banna in Yunnan Province, and newly developed ecological farms. Economic benefits from ecological farms are also considered and are found to be substantial. A modified form of benefit-cost analysis is proposed for economic valuation of these farms.

Application of Marsh Gas as an Energy Resource in Developing Agri-Ecological Systems,
by Hu Binghung and Huang Zhuangbiao

The production of marsh gas (biogas) from agricultural, human, and animal wastes has helped solve the energy problems in the countryside and promote the development of ecological agriculture. As developed in Shunde County in Guangdong Province, south China, marsh gas production has been integrated into the local agroecosystem; this ecosystem is dependent on fish ponds, silkworms, sugarcane, rice, and pigs. In one brigade over half of the energy used is provided by marsh gas; besides household consumption, the gas is used to generate electricity as well as for other commercial purposes.

Marsh gas production serves several important needs: helps meet household energy needs (one pit can save 850 kg of coal per year); provides a fine, decomposed organic fertilizer for farm use; produces an organic by-product used as a fish food or as a substrate for mushroom production, thereby increasing farm income; and helps improve environmental health by sterilizing waste products during the process of fermentation.

Several problems exist relating to increased marsh gas production. One is the shortage of suitable waste materials for the gas generators; total energy production is still insufficient. Another problem is the long-run ecological impacts of continued pit residue use in ponds and on fields. These are topics for further study.

A Preliminary Observation on the Creation of the Farmland Forest Network and Its Effects in Doumen County in the Pearl River Delta,
by Liu Jihan

The low-lying coastal areas of Doumen County in Guangdong Province, south China, were frequently adversely affected by cold spells, typhoons, high tides, and heavy winds. Rice and sugarcane production were unstable and frequent economic losses resulted. In addition, timber and firewood were scarce and the living standards of local residents were low. An experimental system of tree networks was planted to help protect the agricultural lands.

A series of tree belts was planted using *Casuarina* and *Leucaena*. The main belt was parallel to the beach and subsidiary belts were perpendicular to the main belt. Each belt had from two to four rows of trees, planted from 0.4 to 0.6 m apart. The preliminary results are positive; the forest network has resulted in reduced wind speed behind the belts (reduction varies from 10 percent to 60 percent depending on distance from the tree belt). Air and soil temperature have also been effected, and the net result had been an increase in crop yields. In trial plots the protected fields had yields as much as 55 percent higher than unprotected fields. An economic analysis of the costs of tree planting compared to benefits from increased yields of crops, firewood, and timber indicates that establishing a forest network can have positive net benefits and is thus economically attractive.

Ecological Effects and Economic Results of the Artificial Plant Community,
by Long Yiming and Zhang Jiahe

Recent work is reported on the ecological and economic benefits of multilayered and multispecies plantation developments (artificial plant communities) in Yunnan Province in southwest China. It is found that this mixed planting approach has many advantages over the more traditional monoculture approach practiced in Yunnan.

Two main systems are examined: rubber inter-

planted with tea and rubber interplanted with devil pepper. The main research results are as follows: (1) The mixed cropping patterns partially mimicked natural tropical forests in producing large amounts of plant debris, which improved soil fertility; a rubber monoculture produced considerably less material; (2) The increased plant layering aided in the conservation of water and soil by preventing the damage formerly done by heavy rains on rubber monocultures; (3) Stress from climate and other natural factors was reduced; the mixed communities are more resilient; (4) Economic returns were found to be greater under the mixed communities. Not only were two or more crops produced but rubber output even increased slightly in comparison to its monoculture yield. Other savings also resulted from the improved soil and water conservation features mentioned earlier.

A Preliminary Study of Ethnobotany in Xishuang Banna,
by Pei Shengji

Ethnobotany, the study of direct interrelationships between humans and plants, focuses on the perception of and uses of plants by different human populations. Based on more than twenty years of research in Xishuang Banna in southern Yunnan Province, an extensive listing of plants and their uses has been developed.

Plants can be used as sources of food, clothing, shelter, or medicine, as well as serve social functions with respect to literature, the arts, religion, and even folklore. In this respect Xishuang Banna is a particularly rich area for research. Bordering Burma and Laos, this area contains some of China's last undisturbed tropical rainforests. Xishuang Banna is ethnically very diverse. The largest group is the Dai, followed by the Hani (Aini), and various smaller national minorities. Since the various groups inhabit different parts of the environment (from river valleys to steep mountain slopes), their awareness of and use of plants varies considerably. The Dai people, for example, have a tradition of forest preserves for each village, as well as family homegardens around each house. The study lists 218 plant varieties that were frequently used by the various nationalities included in the survey.

The Biological Control of Insect Pests and Insect Pest Management in China,
by Pu Zhelong

Insect pests are a major cause of agricultural losses in China and, to combat this, biological controls of insect pests are being used increasingly. These controls can be grouped into four broad categories: (1) the mass raising and release of parasitoids and predaceous insects; (2) the introduction of parasitoids and predaceous insects from abroad or from other areas of the country; (3) the use of predaceous microbes; and (4) the use of beneficial birds. Many examples are given on the use of biological control in various regions in China to protect field crops, orchards, forested areas, and plantations.

Besides biological controls, in the past twenty years insect pest management has been used for the control of agricultural and forest insect pests. These methods include the integrated application of agricultural, chemical, biological, and physical controls to reach the dual goals of insect pest control as well as decreased environmental pollution. Examples of such control practices for the oriental migratory locust, rice pests in south China, and cotton insect pests are given.

The Correlation Between the Exploitation of the Tropical Forest in Southern Yunnan and the Water and Soil Conservation,
by Wang Huihai, Ma Weijun, Den Shunzhang, and Li Dehou

Runoff experiments were conducted over a six-year period to determine the effects of various variables on soil erosion in reclamation areas and tropical forests in southern Yunnan Province, southwest China. Among the variables considered were cultivation methods, plant community structure, vegetation types, and land utilization patterns. Particular attention was paid to the effects of slash-and-burn cultivation in this area.

The original tropical forest is characterized as multilayered and multispecies. Southern Yunnan has a tropical climate with distinct wet and dry seasons. Field tests were done on 20 m by 5 m plots and water and soil runoff were measured. Significant results were found with respect to most variables; in particular, results were obtained on the correlation between soil erosion and such variables as season, rainfall characteristics such as intensity and timing, and cultivation practices and crop cover. Terracing was found to be very useful in decreasing soil erosion as was the intercropping of perennial crops such as rubber and tea. Slash-and-burn fields had the most serious erosion problems and would benefit greatly from the use of terraces.

A Study of the Basic Theory and Technical Methods to Assess the Efficiency System of Forests,
by Zhang Jiabin

Forests provide many goods and services to society. Among these are water and soil conservation, tourism, forest flora, wildlife, and climate regulation. A study of the "efficiency system" of the forests, or the economic efficiency with which these goods and services are provided, has been carried out in Yunnan Province in southwest China. The study analyzes separate components of the forestry system—firewood production, fertilizer from swidden burning, timber and lumber, water and soil conservation—and, finally, general environmental protection.

These various factors are evaluated in an economic framework that examines the costs of replacing forest products by either establishing new forests or by using substitute sources (for example, coal or hydropower could replace firewood). Labor and money costs are used to compare various alternatives in a benefit-cost framework.

Each class of forest product is evaluated in turn, and estimates are derived of the annual value of each good or service produced by the forest. These range from 154 *yuan* (about $80) for soil conservation per *mu* of land (15 *mu* per ha), to 32 *yuan* per *mu* for fuelwood to 0.3 *yuan* per *mu* for fertilizer.

The Ecological Patterns in the Field-Pond System of the Low Lying Sandy Land of Both Sides of the Zhujiang (Pearl River) Estuary,
by Zhong Gongfu, Qin Wenging, and Huang Facheng

Low-lying areas of recently formed land in the Pearl River Delta were frequently flooded, thereby hampering agricultural production. A field-pond system has been developed that allows high yields of rice, sugarcane, and pond fish. In this system low-lying fields are dug out to form ponds, and the soil removed in the process is placed on nearby fields, thereby elevating them. A complex ecosystem has developed around this interaction of fields and ponds.

The peasants in this area have found that this system can raise a field's level up to sea level in three to five years, thereby reducing the harmful effects of waterlogging and salty tides. Other parts of the ecosystem include the use of green fodder and pig or poultry waste as fish feed and a rotation between rice, sugarcane, and green manure in the elevated fields. The ratio of pond to fields is about 1 to 8 or 9 and both parts of the ecosystem, the aquatic and terrestrial, interact and benefit the other. For example, the use of pig excrement has doubled the per-*mu* production of fish ponds. In turn, the pond muck is used to elevate and fertilize fields, which in turn produce fodder for the pigs. In this way the land and water resource interact and use solar and human energy to increase agricultural production.

Ecosystem Models for Development: An Introduction to Human Ecology as a Methodology for Development Research, Planning, and Analysis,
by A. Terry Rambo

Rural development is seen simultaneously as a social problem and an ecological problem. Thus, research by both social and natural scientists is required to develop suitable solutions. An appropriate conceptual framework is needed to integrate the work of scientists in these diverse fields, however. Human ecology, with its dialectical view of the relationship between human society

and the natural environment, offers a comprehensive framework for organizing research on rural development.

From the perspective of human ecology, the human social system and its ecosystem are seen as being involved in dynamic interaction in which change in one system causes change in the other, which then results in further change in the first system, and so on in an endless dialectic. Interaction between the two systems can be analyzed in terms of flows of energy, materials, and information. Focusing on these flows provides a common set of analytical categories for both natural and social science researchers.

Employing such a complex systems model of rural development is not simple, but then the real world of rural Asia is not simple either. It can be argued that many serious mistakes in past efforts at rural development reflect imposition of overly simple analytical models on social and ecological systems whose real complexity we are just beginning to understand. This complexity is illustrated with a case study of social and environmental problems encountered in attempts to develop upland areas in Vietnam.

Agricultural Ecology Research in Northeast Thailand: The Rainfed Cropping Systems,
by Terd Charoenwatana

Northeast Thailand, home to seventeen million people, contains about one-third of the total area and population of Thailand. It is also the poorest region in Thailand and more than 80 percent of the population is engaged in agriculture—mostly small-scale farmers on rainfed land. The Rainfed Cropping System Research Project began in 1975 and examines how the available resources can be better used to increase farm income.

Since irrigation can at most cover 15 percent of the agricultural land, the project examines the four major rainfed agroecosystems within the Korat triangle to determine what cropping patterns are technically possible, socially acceptable, and economically profitable. By combining tests in experimental stations and farmers' fields, intercrops and various double cropping systems were developed to replace the previous monoculture of rice, cassava, or kenaf. Several promising cropping patterns are described as well as the climatic, agronomic, and social requirements for their successful use.

Identifying Key Questions for the Development of Ecosystems,
by Gordon R. Conway

In order to improve cross-disciplinary work when addressing an ecosystem, a set of organizing concepts or frameworks is proposed to encourage scientists to interact with one another in a way that produces insights that significantly transcend those of their individual disciplines. Based on research conducted in Thailand, the *ecosystem* is used as this organizing framework. The ecosystem can range in size from an individual rice field to a farm, village, or region.

The system is analyzed in a series of steps: statement of objectives, system definition, pattern analysis and exploration of system properties, identifying key questions, and then research design and implementation. These steps help illuminate the operation of the system, which can then be described in terms of a number of system properties. These properties describe how an ecosystem operates over time. *Productivity* is a measure of output or yield. *Stability* is concerned with the variability of yield or output. *Sustainability* is a related concept and refers to the resilience of a system to stress or perturbations. Finally, *equitability* measures the distribution of income or production among the farmers.

Using Benefit-Cost Analysis to Evaluate Alternative Strategies for Developing Tropical Ecosystems,
by John A. Dixon and Wang Yiting

Economic analysis can provide a useful framework for evaluating alternative development strategies. In particular, benefit-cost analysis is becoming widely used to determine the benefits and costs of different development options. When used as an aid to decision making, benefit-cost analysis (BCA) can be a powerful tool. A three-step process is outlined whereby a project is

quantified, valued, and *appraised.* Quantification identifies all of the goods and services that go into and are produced by a project. These flows are then valued and monetary values are assigned (to the extent possible). The formal appraisal then uses the information previously generated to carry out a BCA.

A number of key concepts including definition of project boundaries, the choice of an appropriate time horizon, discounting, risk and uncertainty, and irreversible results are discussed. An example based on land use alternatives in Indonesia is presented.

The applicability of BCA in China is also discussed. Attention must be paid to China's social and economic conditions, but since the goal is the efficient allocation of resources, BCA can also be used in China. Problems relating to price determination, project boundaries, and data available in China are covered.

Cultural Beliefs and the Management of Agroecosystems,
by George W. Lovelace

Human interactions with the environment are influenced and governed by a wide spectrum of factors, ranging from ones of a purely biophysical nature to others that are almost entirely sociocultural in nature. Of these, ideational factors (such as cultural beliefs or values) are probably the least examined and understood. Yet, it is such factors that make the human ecological experience unique.

The discussion focuses upon the roles that ideational factors often play in determining the nature of human-environmental interactions, especially in connection with traditional rural societies. Cultural belief and value systems are seen to serve not only as "storehouses" of environmental knowledge and wisdom, the maintenance and transmission of which is important to the stability of the society and its environmental interactions, but also as strong motivating forces in environmental modification.

The importance of traditional beliefs and values in the adaptation and interactions of traditional societies to their environments has implications for rural development and modernization programs. The environmental information contained within these systems, for example, can often be usefully employed in development-related work.

Agricultural Development and Quality of Life,
by Joseph P. O'Reilly

Recent approaches to assessing the impact of development programs on the quality of family and community life are discussed. This quality of life (QOL) approach focuses directly on human communities while other approaches, including economic or ecological ones, focus on monetary or physical effects. One emerging methodology is that of Farming Systems Research and Development; this approach recognizes the interdependence of human and ecological factors.

There are many definitions and measures of QOL. Some definitions focus at the microlevel, that of an individual, while others deal with society as a whole. Social indicators are frequently used to measure QOL; the indicators relate to a wide variety of human needs (food, shelter) or states (health, security, peace). Other measures, such as GNP, are also used but may overlook important equity considerations. Growth without equity may actually lead to a decrease in overall QOL. A final approach for evaluating development is Social Impact Analysis; this technique uses social indicators to evaluate development alternatives.

Population Dynamics, Agroecosystems and Agricultural Innovation,
by Peter Pirie

Major theoretical and empirical studies on the relationships between population and agriculture are reviewed. Research on the relationship between access to land resources and fertility suggests, for example, that ownership, hereditary rights, conditions on the use of land, and distribution of rights are all important variables. Consistent patterns are elusive, however, and changes in technology may often modify the relationship between fertility and the physical and institutional availability of land.

Lack of progress in understanding interactions between population dynamics and agricultural change reflects both the inadequacy of theoretical constructs and the politicization of demography. The systems view associated with ecology has only recently displaced the determinist and possibilist models, which inhibited earlier attempts to explore causal relationships. Linkage of demographic questions to particular religious and political ideological positions in both capitalist and socialist societies has been detrimental to carrying out objective empirical research. The views of Malthus, which were articulated in reaction to the French Revolution, were the ideological basis for the assumption that fertility control was always the prerequisite for rural development. Some of Marx's writings supported the opposing view that changes in economic institutions must always precede population change.

More carefully designed empirical research, taking advantage of the vastly increased availability of reliable data on population and agricultural resources, offers a means to escape endless sterile ideological debate and establish more objective understanding of critical relationships between population dynamics and agricultural innovation and development.

Agricultural Land Development and Forest Clearance in Peninsular Malaysia, by Rokiah Talib

Land development policies in Peninsular Malaysia have centered on the clearing of tropical forests for conversion to agricultural production, usually for perennial crops such as rubber or oil palm. These newly opened areas were then settled by poor people with the goal of increasing their average income. While the short-term socioeconomic benefits of converting forest to agricultural use cannot be denied, the land use policies had little regard for long-term ecological implications.

Two methods of land clearance and crop establishment are compared with respect to their environmental and ecological effects as well as their economic benefits. The first method is the most common pattern developed by the Federal Land Development Authority (FELDA). It is capital-intensive and uses private contractors who rely extensively on heavy machinery. While land clearing is rapid, the forest biota is lost and the soil may be negatively affected. Long-term social dependency of the settlers on the government is also a consequence. An alternative strategy developed in the state of Kelantan relies heavily on the use of hand labor and simple tools in a slash-and-burn process. The two methods produce different results with respect to speed of land clearing and average farm size. While the Kelantan approach is less damaging to the environment, net farm incomes are also probably smaller. On the other hand, settler communities appear to be relatively highly integrated and autonomous.

Ecological Approaches to Managing Degraded Uplands in the Philippines, by Percy E. Sajise

The hilly uplands of the Philippines are characterized by steep topography (>18 percent slope), marginal productivity, general rainfall dependency, and impaired hydrologic characteristics. These uplands cover 30 percent of the total country and are home to about 5 million people. The poor upland resource base affects not only these residents but also adjacent lowland communities through floods and siltation.

Both the biophysical and sociocultural components of the upland system need to be considered in developing management plans. An ecological management approach is outlined that considers various components: topography, soil fertility, hydrologic characteristics, use of fire, plant competition, pest problems, and sociocultural constraints. Based on these considerations several upland regeneration strategies are outlined: a low-input legume-based strategy using *Leucaena leucocephala* in an agroforestry program; a forage-legume and livestock (goats) production scheme; and a *Leucaena*-based upland cropping system combining strip planting of *Leucaena* with upland rice and other annual crops. All of these strategies are productive, ecologically sound, and socially acceptable.

Systems Analysis of Agriculture in the Chiang Mai Valley,
by Manu Seetisarn

A multidisciplinary approach is used to investigate the problems of multiple cropping in the Chiang Mai Valley of northern Thailand. A systems analysis framework is adopted to incorporate both the various ecological-agronomic-social dimensions of multiple cropping and the various academic disciplines needed to analyze these agricultural systems. The Multiple Cropping Project was initiated in 1969, but early agronomic results were only partially adopted because the sociocultural side had been ignored. When the broader systems analysis approach began in 1978, a deeper understanding of the farm system and the constraints faced by farmers developed.

The Chiang Mai Valley was studied as a paddy land agroecosystem. More than twenty different cropping systems are practiced in the valley, each dependent on the interaction of many local factors such as soils, water supply, climate, population, farm size and land tenure, transportation and markets, and government policies. Both risk aversion and responses to changing environmental or economic factors lead to changing cropping patterns. The performance (or property) of the system is the result of the interaction among various components. Although productivity may have been the traditional performance indicator used by scientists, farmers may be equally concerned with stability and sustainability.

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